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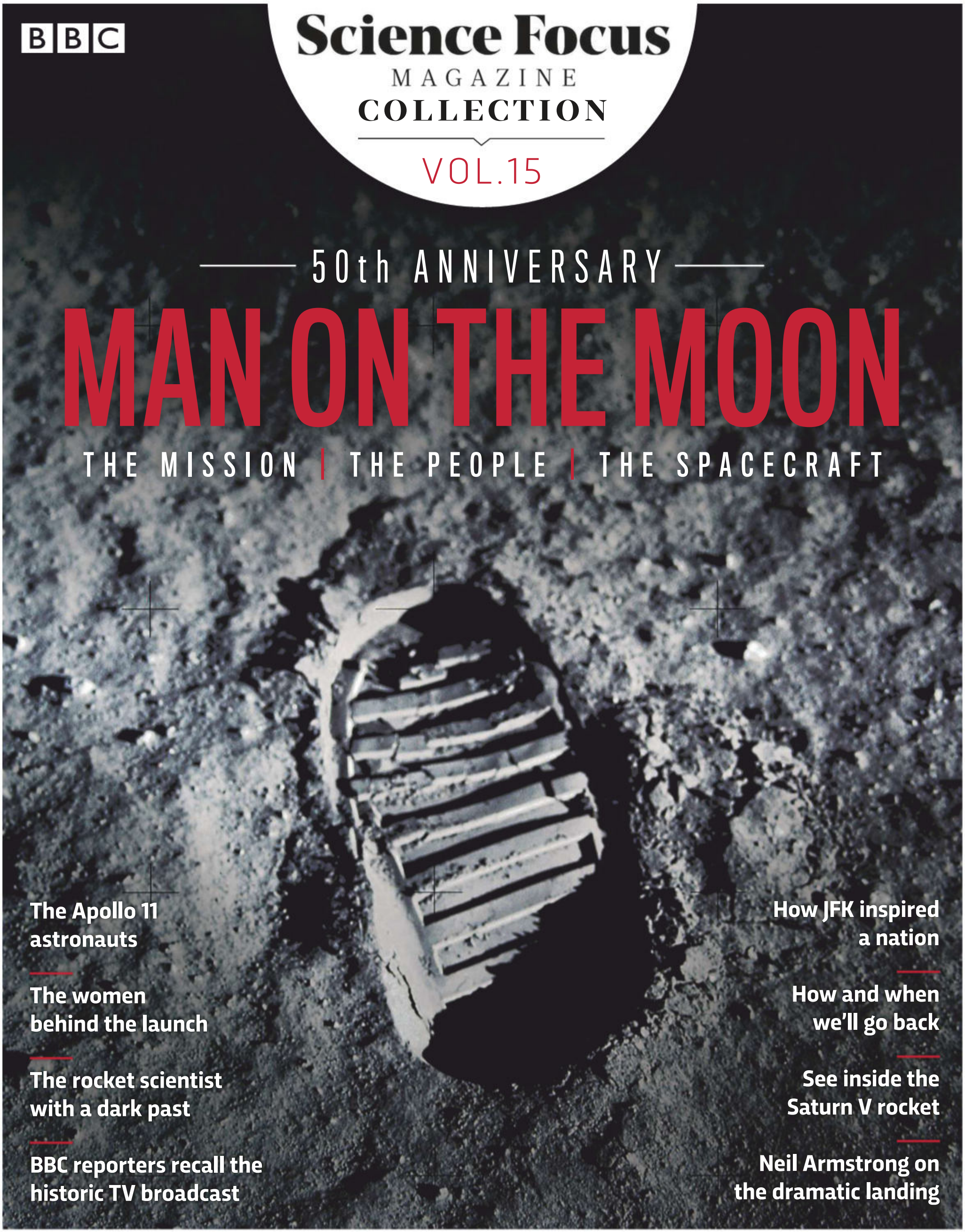
Science Focus MAGAZINE COLLECTION

VOL.15

50th ANNIVERSARY

MAN ON THE MOON

THE MISSION | THE PEOPLE | THE SPACECRAFT



The Apollo 11 astronauts

The women behind the launch

The rocket scientist with a dark past

BBC reporters recall the historic TV broadcast

How JFK inspired a nation

How and when we'll go back

See inside the Saturn V rocket

Neil Armstrong on the dramatic landing

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Risk versus reward

I can't look at the Moon without being reminded of Neil Armstrong and Buzz Aldrin – I'm old enough to remember watching the flickering black and white images of Armstrong taking his 'one small step' on TV.

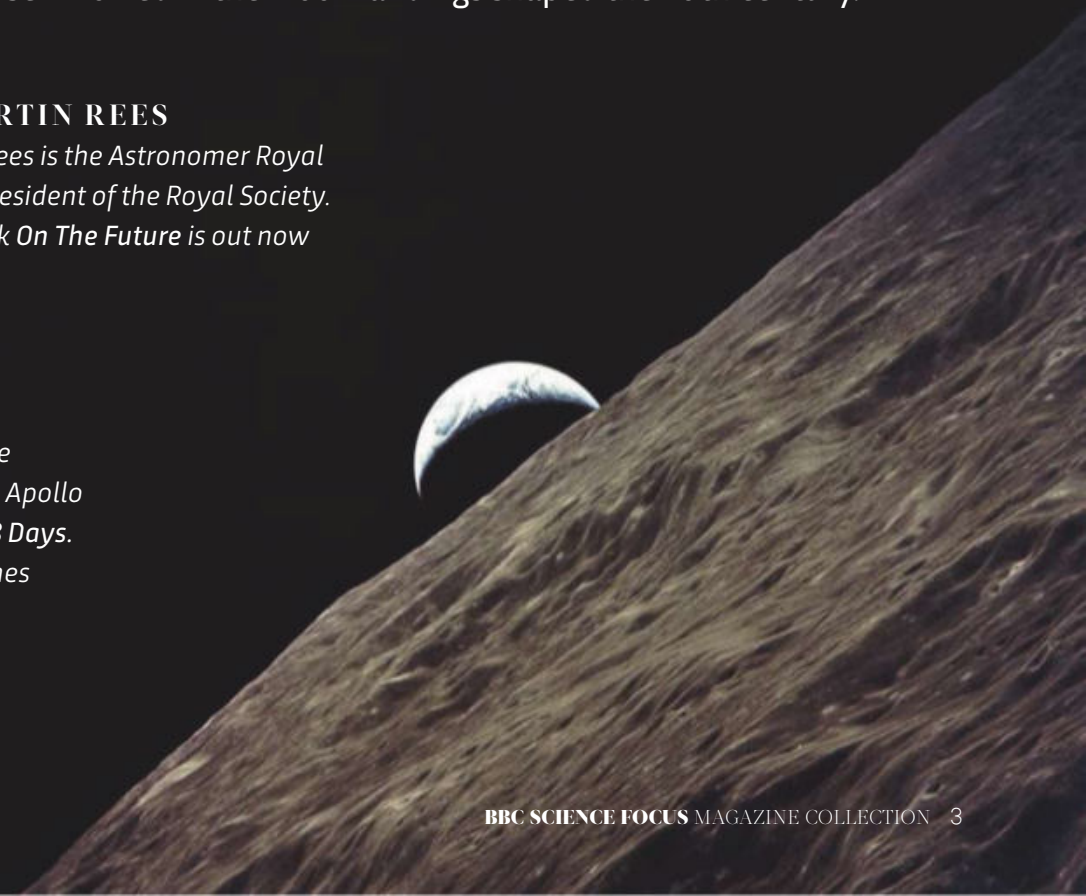
The success of Apollo 11 now seems even more remarkable (and the astronauts even more heroic) given how the mission depended on primitive computing and untested equipment. Despite NASA making every effort to ensure their safety, the Apollo 11 crew was still risking everything by blasting off aboard the enormous Saturn V rocket. Indeed, President Nixon's speechwriter William Safire had drafted a speech to be given if the astronauts ended up stranded on the lunar surface.

Had the momentum of the space race been maintained, there would surely be footprints on Mars by now. But once that race was won, there was no motivation for continuing the requisite expenditure to send people to the Moon. Hence, it's been 47 years since a human has ventured beyond Earth's orbit. But that's set to change. Another space race is gearing up, this time between China and America. And there's also a host of other nations and private enterprises looking to follow in their wake. It seems the rewards of space – knowledge, resources and potentially a long-term future for the human race – are once again worth the expense and risk.

It's dangerous, however, to think that space offers an escape from Earth's problems. Any that we don't face and solve here, we'll take into space with us. Coping with climate change may seem daunting, but it's a doddle compared to terraforming Mars. No place in our Solar System offers an environment even as clement as the Antarctic or the top of Everest. There's no 'Planet B' for risk-averse people.

Nevertheless we should celebrate and encourage the new space adventurers, because they will have a pivotal role in shaping what happens in the 22nd Century and beyond. Just as Armstrong, Aldrin and everyone else involved in the Moon landings shaped the 20th Century.

LORD MARTIN REES
Lord Martin Rees is the Astronomer Royal and former president of the Royal Society. His latest book ***On The Future*** *is out now*



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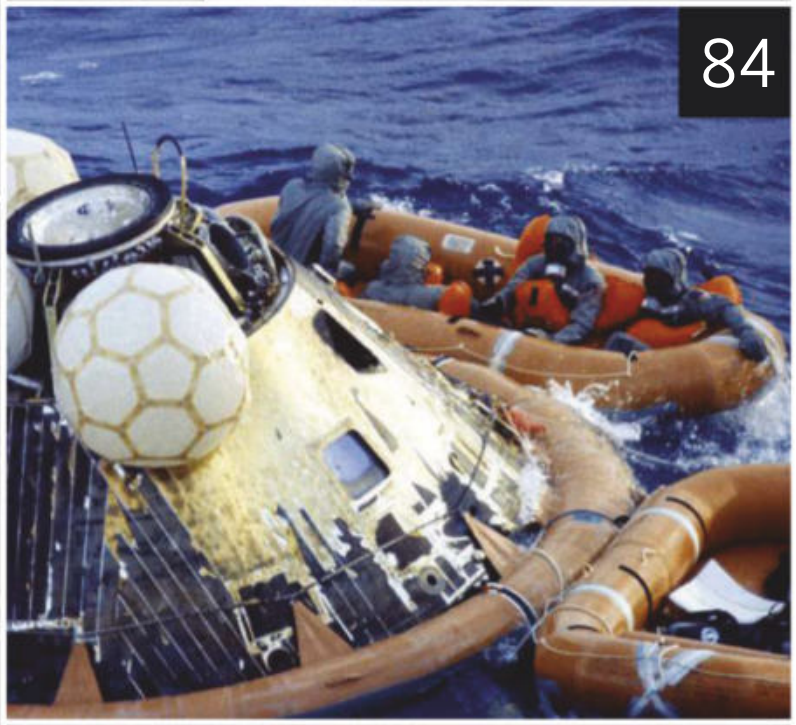

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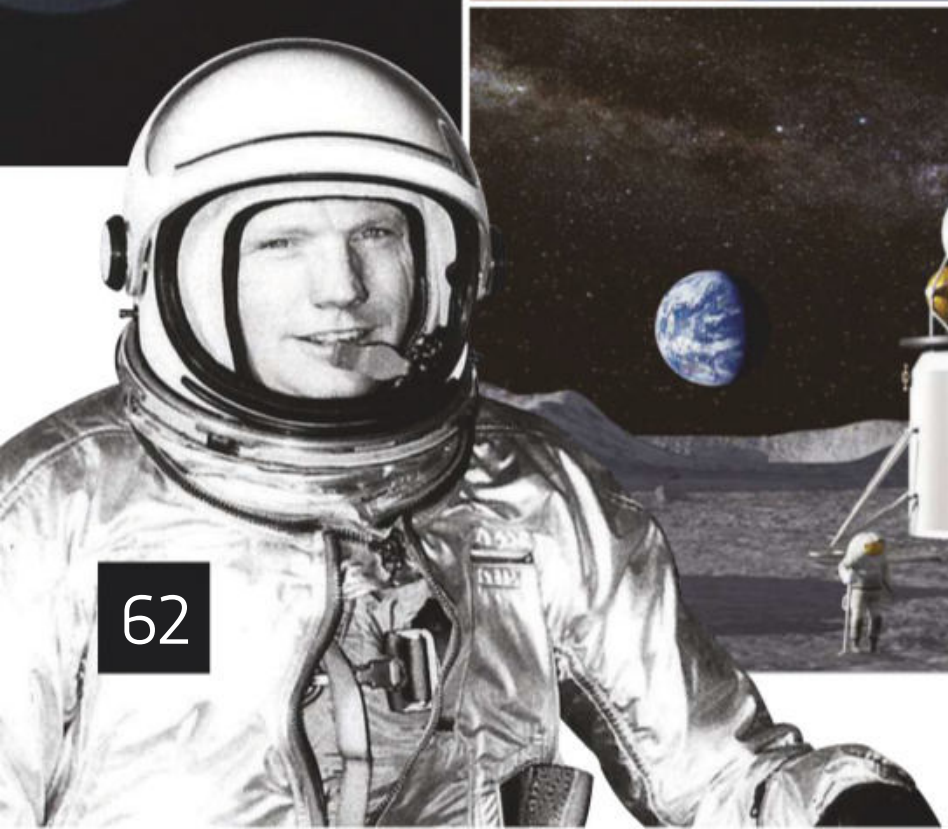

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PREFLIGHT

TOUCHDOWN

RETURN

1967

California

THE FLYING BEDSTEAD

Neil Armstrong practises flying the lunar landing research vehicle (affectionately known as the 'flying bedstead') at NASA's Dryden Flight Research Center at Edwards Air Force Base. This single-engined contraption would form the basis of the craft that Armstrong would land on the Moon two years later.

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PREFLIGHT

The ultimate prize: America and the Soviet Union competed to be the first nation to reach the Moon

SHOOTING FOR THE MOON

There was more riding on the outcome of the space race than historical prestige and national pride. The political ideologies driving the Cold War were competing for the ratification that being the first to set foot on the lunar surface would bestow

words by DOMINIC SANDBROOK and PIERS BIZONY

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Five decades after Neil Armstrong spoke the words, "Houston, Tranquility Base here. The Eagle has landed," they still have the power to send shivers down your spine. With them, he told NASA's mission control and an audience of almost 600 million people watching around the world that his lunar module had touched down on the surface of the Moon.

What happened on 20 July 1969, when Armstrong and Buzz Aldrin became the first men to walk on the grey, powdery surface of the Moon, was a landmark in human history – a "giant leap for mankind", in Armstrong's famous words. But, as Aldrin told television viewers the night before the astronauts returned to Earth, the Apollo 11 mission was also the reward for years of "blood, sweat and tears" from "thousands and thousands of people… who built the spacecraft; who did the construction, design, the tests, and put their hearts and all their abilities into those craft."

It set the seal on years of hard work, inspired not only by technological curiosity and the human thirst for knowledge, but also by the ideological passions of the Cold War.

What is all too easy to forget about Apollo 11 is that it was the fifth manned spaceflight in NASA's Apollo programme, and the third to travel to the Moon after Apollo 8 and 10, which had both orbited without landing. It was the climax of years of effort and dedication, in which NASA inched steadily closer to our celestial neighbour, driven by the fear that the Soviets would get there first.

THE IMPORTANCE OF BEING FIRST

The roots of the space race lay in two distinct sources: first, the extraordinary advances in rocketry made in the first half of the 20th century, often with German scientists at the forefront (notably the V2 designer Wernher von Braun, who went on to design the Apollo programme's Saturn V rockets); and second, the political passions of the Cold War.

Since the late 1940s, the Western and Communist worlds had been locked in a bitter ideological, economic and military rivalry, a struggle not just of two great power blocs, American and Soviet, but of two systems that both claimed to represent the future of human society. Victory in the space race – marked by the first satellite, the first astronaut, the first spacewalk or the first lunar landing – would mean a gigantic propaganda coup for the nation that could achieve it. And when first blood went to the Russians, after the Sputnik launch in 1957 and Yuri Gagarin's space flight four years later, the pressure was on the Americans to follow suit.

The powerhouse behind the American space programme was the National Aeronautics and Space Administration (NASA), created as a government agency in July 1958. Crucially, it was a civilian agency, not a military one,

TOP: The Mercury Seven, NASA's first astronauts, introduced to the world on 9 April 1959

ABOVE: Wernher von Braun, the controversial designer of the Saturn V

RIGHT: Yuri Gargarin became the first man in space in April 1961

Since the late 1940s, the Western and Communist worlds had been locked in a bitter ideological, economic and military rivalry

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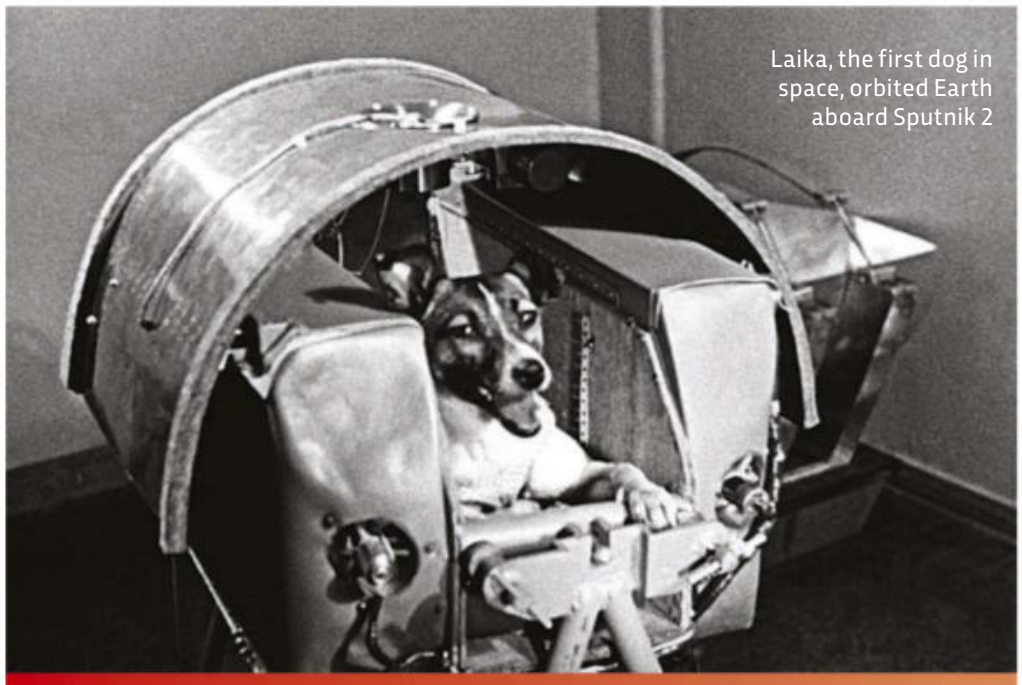


Laika, the first dog in space, orbited Earth aboard Sputnik 2

RED STAR RISING

When the Soviet Union launched Sputnik 1, the world's first artificial satellite, in October 1957, the Cold War moved into space. Until the late 1950s, Western observers assumed that American technology was far ahead of its Soviet equivalent. But the Sputnik programme had become a matter of national pride for its Russian architects, a way of proving that their country had recovered from the war and that the Communist system would triumph over the capitalism of America.

In the United States, the reaction was fear and shock: congress rushed to pass the National Defense Education Act, redesigning the school curriculum and authorising $1 billion in extra spending to boost American science and technology.

Over the next few years, though, it was the Russians who led the way in an intensely competitive parallel to the arms race – the space race. In November 1957, Sputnik 2 made Laika the first dog in space, although she died just hours after take off. And in April 1961, Yuri Gagarin became the first man to orbit the Earth. He realised the dreams of generations who had stared up at the skies, and of the Soviet leadership, desperate for a propaganda coup. As the 1960s progressed, however, NASA not only drew level but pulled ahead. With the Cold War at its height, victory in the space race had become a national priority. To American officials, Sputnik, Laika and Gagarin had been embarrassing defeats and they were determined to have the last laugh.

Sputnik 1, the first artifical satellite, was launched into space in 1957

which made it easier to attract left-leaning scientists, but also meant occasional tensions with the Pentagon. Its first major programme was Project Mercury, which ran from 1959 to 1963 and was designed to put the first American astronaut in orbit. Mercury reached fruition in February 1962, with Mercury-Atlas 6, which orbited the Earth three times and made its pilot, Marine Colonel John Glenn, a national icon.

By this time, however, the goal had changed dramatically. Gagarin's space flight in April 1961 had deeply shaken morale in the White House, and a few days after it Vice President Lyndon Johnson reported to President John F Kennedy that, "…we are neither making maximum effort nor achieving the results necessary if this country is to reach a position of leadership" in the space race.

PICKING UP THE PACE

Since Kennedy was a committed Cold War warrior who had won office months earlier promising a new age of dynamic, aggressive leadership, he decided to act. On 25 May 1961, addressing a joint session of Congress, he committed the administration to, "…achieving the goal, before this decade is out, of landing a man on the Moon and returning him safely to the Earth." No other space project, he added, "will be more impressive to mankind, or more important in the long-range exploration of space; and none will be so difficult or expensive to accomplish."

Kennedy's pledge transformed the space race almost overnight. At the time of his speech, Glenn's flight was still months away, and NASA seemed to be lagging behind its Soviet counterpart. Even some NASA employees, while delighted by Kennedy's commitment, wondered whether his timetable was realistic. But his rhetoric struck a chord in an affluent nation reared on tales of American exploration and the conquest of the frontier. And now, with a $25 billion funding commitment and 400,000 new jobs, the space programme had the chance to realise the President's ambitions.

The first step was Glenn's successful space flight. Next, the Mercury programme gave way to Project Gemini's 10 manned flights in 1965 and 1966 and pioneered more advanced techniques such as in-flight radar, docking, rendezvous and an artificial horizon. All the time, NASA scientists were conscious of the pressure of Kennedy's deadline, as well as of events outside the laboratory, such as the Vietnam War, which made American success in the space race all the more urgent.

Yet so big were the budgets, and such was NASA's technical expertise, that progress was astonishingly swift. By October 1968, the first manned Apollo mission – an 11-day flight to test the new command module – was ready to take off. Three more missions were scheduled before July 1969. Month by month, America's space pioneers were edging towards their goal.

Russian progress, meanwhile had been thrown into chaos by the death of Sergei Korolev, the Soviet Union's chief rocket designer, in January

ABOVE: President John F Kennedy addresses Congress on 25 May 1961

ABOVE RIGHT: Gemini 7, as seen from Gemini 6A as the NASA craft approaches its partner for an orbital rendezvous in 1965

RIGHT: NASA chief James Webb ensured everyone got behind the spider-like design for the lunar lander

NASA/JSC X3

TIMELINE USA vs USSR: THE RACE TO THE MOON

USA

6 DECEMBER 1957
First satellite launch attempt with a Vanguard rocket fails.

31 JANUARY 1958
A Juno 1 rocket puts the Explorer 1 satellite into orbit.

1 OCTOBER 1958
New space agency NASA begins operations.

9 APRIL 1959
The astronauts of the Mercury programme are introduced.

11 AUGUST 1960
Images of space are returned from orbit for the first time.

USSR

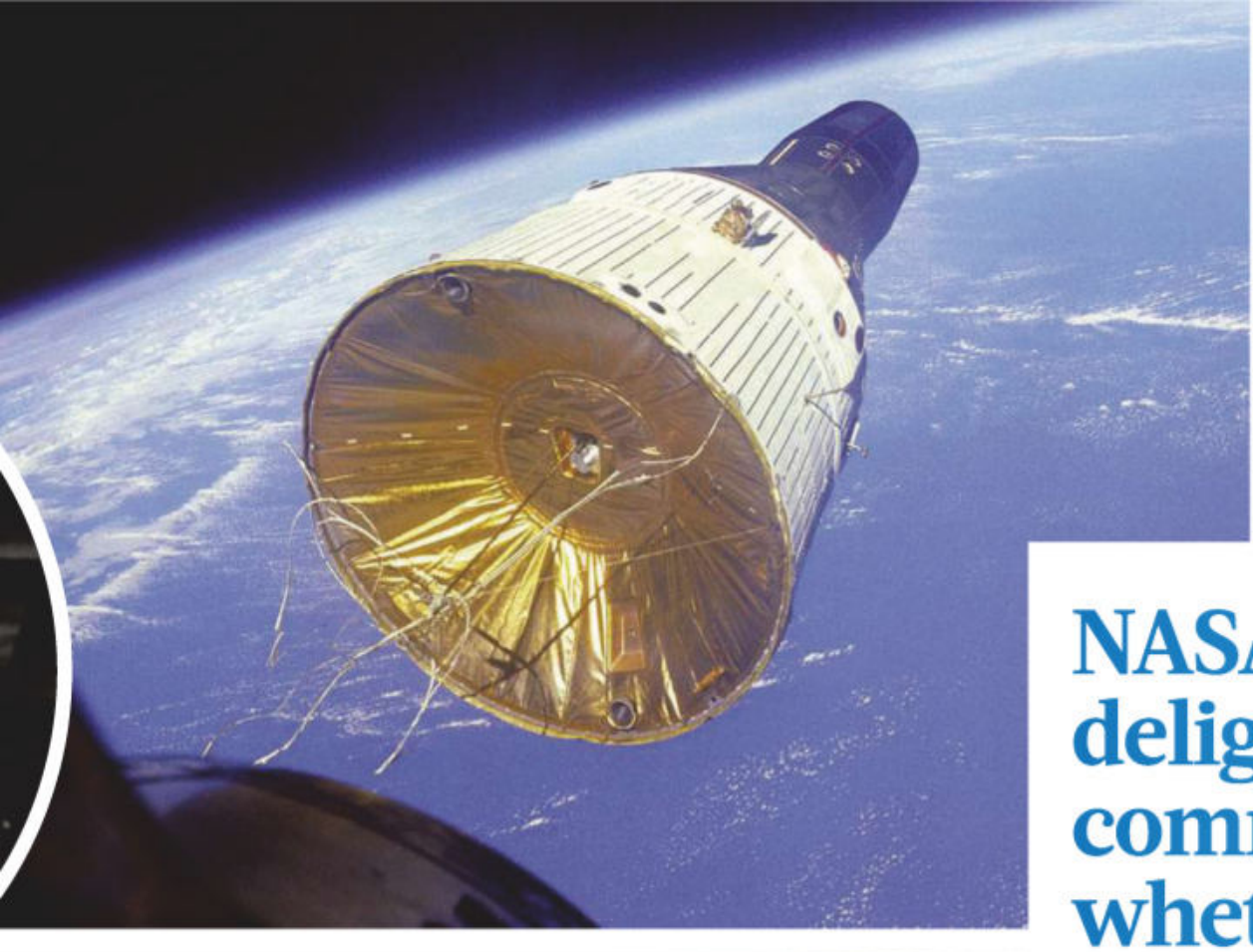
4 OCTOBER 1957
Sputnik 1 launches into Earth orbit. The Space Age has begun.

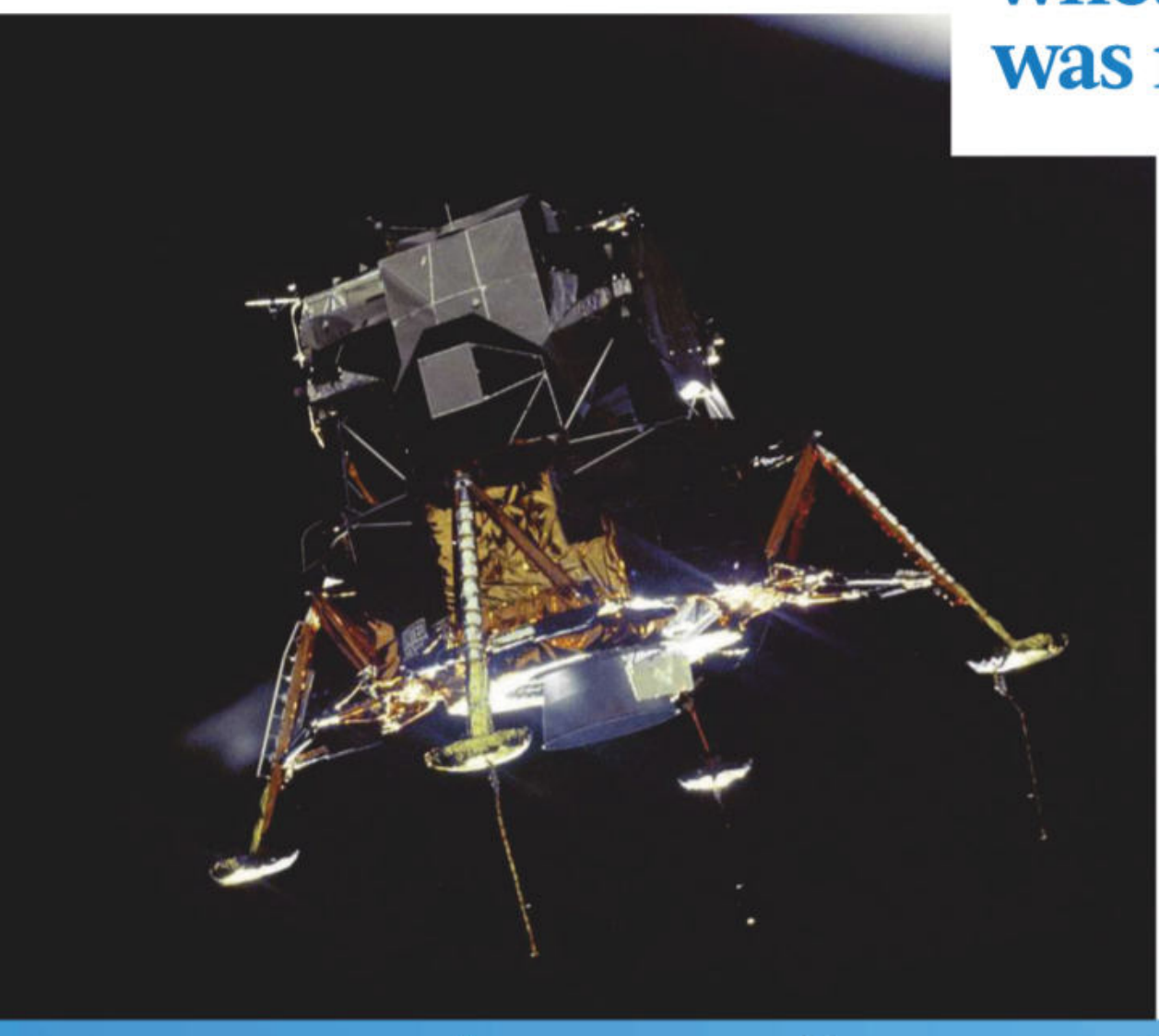
3 NOVEMBER 1957
Sputnik 2 launches into space carrying Laika the dog.

15 MAY 1958
Sputnik 3, weighing over a tonne, launches into orbit.

2 JANUARY 1959
Luna 1 misses the Moon, but leaves Earth orbit for the first time.

14 SEPTEMBER 1959
Luna 2 hits the Moon after its launch two days earlier.





NASA employees, while delighted by Kennedy's commitment, wondered whether his timetable was realistic

1966. With Korolev at the helm, the Soviet space programme had made great strides thanks to his unifying vision but in the absence of his leadership, rival schemes emerged for sending cosmonauts to the Moon. One team wanted to try for a landing, another believed a circumlunar flight without a landing was a more realistic goal.

In contrast, NASA in the 1960s was under the leadership of James Webb, a determined and focussed administrator who made sure that just one approach was chosen for America's attempt on the Moon. Many people, including Saturn V mastermind Wernher von Braun, had different ideas about the mission, but Webb put his faith in Apollo's spider-like lunar lander. He insisted that everyone within NASA had to support that design or leave.

Despite the Soviet programme being in disarray, there remained a reasonable chance that it could send an adapted Soyuz spacecraft around ➲

24 OCTOBER 1960
Explosion of R-16 rocket on the launchpad kills 126 engineers.

31 JANUARY 1961
Ham the chimpanzee makes a successful suborbital flight.

6 JANUARY 1961
Six candidates shortlisted for first manned flight to space.

5 MAY 1961
Alan Shepard makes a 15-minute suborbital space flight.

9 MARCH 1961
Vostok capsule returns dummy cosmonaut and dog safely from orbit.

25 MAY 1961
President Kennedy announces his plans to send men to the Moon.

12 APRIL 1961
Yuri Gagarin becomes the first man in space aboard Vostok 1.

27 OCTOBER 1961
Saturn I rocket launch marks the start of the Apollo programme.

6 AUGUST 1961
Gherman Titov spends a whole day in space in Vostok 2.

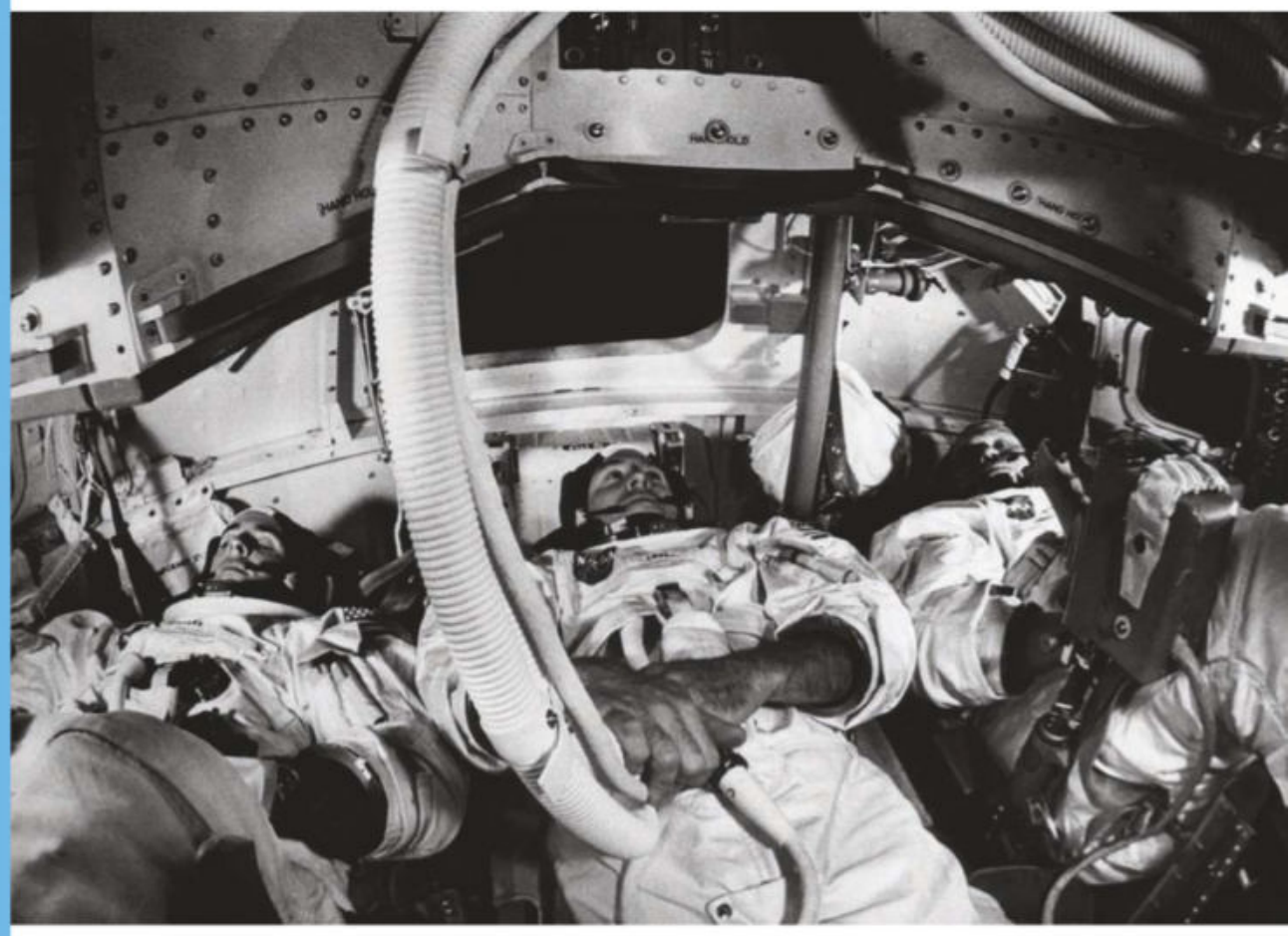
20 FEBRUARY 1962
John Glenn spends five hours in space orbiting the Earth.

1968: THE US TAKES A CHANCE

In 1968, NASA was still recovering from the previous year's Apollo 1 tragedy, in which a fire ignited in the command module during a preflight test on the launchpad, killing the Apollo programme's first crew: Gus Grissom, Ed White and Roger Chaffee. Despite the disaster, the programme was still proceeding and the Apollo 7 mission saw a successful manned Earth orbital mission of the Apollo capsule in October 1968, proving that it was now ready for longer test flights. The same could not be said of the full-scale Saturn V rocket, however. Unmanned tests revealed serious problems with its engines and control systems. Even so, NASA committed a human crew to the rocket's next flight.

NASA administrator James Webb was under immense strain, trying to protect the programme's reputation after the Apollo 1 disaster. When staff suggested flying a Saturn V, with a crew on board, all the way to the Moon, his initial response was: "Are you out of your mind? You're putting our agency and the whole Apollo project at risk!" Then he looked at the latest intelligence reports from Russia and realised there was no choice but to get NASA astronauts to the Moon as fast as possible.

The Apollo 8 crew of Frank Borman, Bill Anders and Jim Lovell, made a circumlunar voyage during Christmas 1968, flying a relatively untested capsule on a full-scale Saturn V rocket that had spun out of control on its last test. The mission could easily have gone wrong. If it had, the Soviet Union might well have pushed on to make its secret Zond project a success.



ABOVE: Apollo 8's crew, William Anders, James Lovell Jr and Frank Borman, prepare for their circumlunar flight ahead of its launch on 21 December 1968

RIGHT: On 16 July, 1969 NASA's Apollo 11 mission launches from Cape Canaveral (then known as Cape Kennedy), Florida, to start its journey to the Moon

NASA/JSC, ALAMY

the Moon (although the capsule would have to be so laden with extra fuel and oxygen that only one cosmonaut could make the journey). If Russia had managed this trip before Apollo's first touchdown, the world may not have cared much about the distinction between a circumlunar trip and an actual landing. Russia would have scored another huge propaganda victory and we can only guess what the geopolitical consequences of such an achievement might have been.

THE LEAD CHANGES HANDS

On 18 September 1968, Russia succeeded in swinging the unmanned Zond 5 spacecraft around the Moon and back to Earth. The capsule splashed down in the Indian Ocean and was successfully recovered. Two months later, NASA announced that its next flight, Apollo 8, would take off a few days before Christmas

23 MARCH 1965
Gemini 3 sees two astronauts orbit Earth and return safely.

3 JUNE 1965
Ed White performs a spacewalk from Gemini 4.

15 DECEMBER 1965
Gemini 6A and 7 make the first orbital rendezvous.

10 AUGUST 1966
Lunar Orbiter 1 launched to take images of the Moon.

27 JANUARY 1967
Apollo 1's crew of three killed by fire in their spacecraft.

12 AUGUST 1962
Vostok 3 and 4 put two people in space at the same time.

16 JUNE 1963
Valentina Tereshkova becomes the first woman in space.

12 OCTOBER 1964
Three-man spacecraft Voskhod 1 launched on a day-long flight.

18 MARCH 1965
Alexei Leonov makes the first spacewalk on Voskhod 2.

14 JANUARY 1966
Chief rocket designer Sergei Korolev dies during routine surgery.

Russia's N1 rocket was in the air for just over a minute before spiralling out of control and exploding

and head straight for the Moon, even though it would carry no lunar landing module. NASA was desperate to get men into the vicinity of the Moon as quickly as possible. The race was closer than many people realised at the time.

The Russian space programme was under just as much pressure as its American rival, who had experienced a number of disasters in its pursuit of progress, including the deaths of the Apollo 1 astronauts Gus Grissom, Ed White and Roger Chaffee in a launchpad fire. To retain their lead in the space race, the Russian engineers had been pushed by the Kremlin into using ever more dangerous versions of the R-7 rocket before rushing ahead with Korolev's design for the N1 – the 30-engined launch vehicle intended to give the Soviets a moonshot.

The N1 flew for the first time on 21 February 1969. It was in the air for just over a minute before spiralling out of control and exploding. It would be the longest flight the rocket ever recorded. A second test flight, on 3 July 1969, was even briefer with the rocket detonating shortly after lift off and destroying the launch gantry.

Less than two weeks later, at 9.32am local time, on 16 July 1969, NASA's Saturn V rocket launched Apollo 11 into the heavens from Kennedy Space Center, Florida. By this time, Kennedy himself was dead, having been assassinated six years earlier. Lyndon Johnson, who took office after Kennedy, had departed public life too, forced from the White House by the turbulent passions of the Vietnam War. Their successor, the Republican Richard Nixon, watched the launch on his Oval Office television, along with millions of viewers around the world. The greatest adventure in human history, a stirring tribute to man's energy and expertise, was underway. **SF**

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Dominic is a historian and author, and presents documentaries for BBC television and radio

by **PIERS BIZONY** *(@PiersBizony)*
Piers is a science journalist and space historian. His latest book is ***Moonshots: 50 Years Of NASA Space Exploration Seen Through Hasselblad Cameras*** *(Voyageur, 2017)*

11 OCTOBER 1968
Apollo 7 launches on an 11-day mission to Earth orbit.

21 DECEMBER 1968
Apollo 8 sends humans around the Moon for the first time.

3 MARCH 1969
Launch of Apollo 9 marks first flight of the lunar module.

18 MAY 1969
Launch of Apollo 10, the dress rehearsal for the Moon landings.

21 JULY 1969
Apollo 11 commander Neil Armstrong takes first step on the Moon.

USA

24 APRIL 1968
Vladimir Komarov killed in the first flight of a Soyuz spacecraft.

18 SEPTEMBER 1968
Zond 5 probe travels behind the Moon and returns to Earth.

30 DECEMBER 1968
USSR abandons the race to the Moon after Apollo 8.

3 JULY 1969
Second launch of 105m tall N1 ends in biggest rocket explosion ever.

14 OCTOBER 1969
Soyuz 6, 7 and 8 carry out first rendezvous of three craft in orbit.

USSR

With the US trailing Russia in the space race, President Kennedy had to rally popular support for an increased American effort

President John F Kennedy had made his case for going to the Moon in an address to congress in May 1961, just weeks after Yuri Gagarin's first orbital flight. But to accomplish the feat that many deemed to be misguided and, in some cases, unnecessary, he needed the support of the American public. He pitched his vision in a speech delivered to 40,000 people gathered at Rice University in Texas and it propelled the nation to a new frontier

"WE CHOOSE TO GO TO THE MOON"

DELIVERED BY **PRESIDENT JOHN F KENNEDY** ON **12 SEPTEMBER 1962**
AT RICE STADIUM, RICE UNIVERSITY, HOUSTON, TEXAS (PRES: KENNETH PITZER)

President Pitzer, Mr Vice President, Governor, Congressman Thomas, Senator Wiley and Congressman Miller, Mr Webb, Mr Bell, scientists, distinguished guests, and ladies and gentlemen: I appreciate your president having made me an honorary visiting professor and I will assure you that my first lecture will be very brief.

I am delighted to be here and I'm particularly delighted to be here on this occasion.

We meet at a college noted for knowledge, in a city noted for progress, in a state noted for strength and we stand in need of all three, for we meet in an hour of change and challenge, in a decade of hope and fear, in an age of both knowledge and ignorance. The greater our knowledge increases, the greater our ignorance unfolds.

Despite the striking fact that most of the scientists that the world has ever known are alive and working today, despite the fact that this nation's own scientific manpower is doubling every 12 years in a rate of growth more than three times that of our population as a whole, despite that, the vast stretches of the unknown and the unanswered and the unfinished still far outstrip our collective comprehension. No man can fully grasp how far and how fast we have come but condense, if you will, the 50,000 years of man's recorded history in

GETTY IMAGES

a timespan of but a half-century. Stated in these terms, we know very little about the first 40 years, except at the end of them advanced man had learned to use the skins of animals to cover them. Then about 10 years ago, under this standard, man emerged from his caves to construct other kinds of shelter. Only five years ago man learned to write and use a cart with wheels. Christianity began less than two years ago. The printing press came this year and then less than two months ago, during this whole 50-year span of human history, the steam engine provided a new source of power.

Newton explored the meaning of gravity. Last month electric lights and telephones and automobiles and airplanes became available. Only last week did we develop penicillin and television and nuclear power, and now if America's new spacecraft succeeds in reaching Venus, we will have literally reached the stars before midnight tonight.

This is a breath-taking pace and such a pace cannot help but create new ills as it dispels old; new ignorance, new problems, new dangers. Surely the opening vistas of space promise high costs and hardships, as well as high reward.

So it is not surprising that some would have us stay where we are a little longer to rest, to wait. But this city of Houston, this state of Texas, this country of the United States was not built by those who waited and rested and wished to look behind them. This country was conquered by those who moved forward – and so will space.

William Bradford, speaking in 1630 of the founding of the Plymouth Bay Colony, said that all great and honourable actions are accompanied with great difficulties, and both must be enterprised and overcome with answerable courage.

If this capsule history of our progress teaches us anything, it is that man, in his quest for knowledge and progress, is determined and cannot be deterred. The exploration of space will go ahead, whether we join in it or not, and it is one of the great adventures of all time, and no nation which expects to be the leader of other nations can expect to stay behind in the race for space.

Those who came before us made certain that this country rode the first waves of the industrial revolutions, the first waves of modern invention, and the first wave of nuclear power, and this generation does not intend to founder in the backwash of the coming age of space. We mean to be a part of it – we mean to lead it. For the eyes of the world now look into space, to the Moon and to the planets beyond, and we have vowed that we shall not see it governed by a hostile flag of conquest, but by a banner of freedom and peace. We have vowed that we shall not see space filled with weapons of mass destruction, but with instruments of knowledge and understanding.

Yet the vows of this nation can only be fulfilled if we in this nation are first and, therefore, we intend to be first. In short, our leadership in science and in industry, our hopes for peace and security, our obligations to ourselves as well as others, all require us to make this effort, to solve these mysteries, to solve them for the good of all men, and to become the world's leading space-faring nation.

We set sail on this new sea because there is new knowledge to be gained, and new rights to be won, and they must be won and used for the progress of all people. For space science, like nuclear science and all technology, has no conscience of its own. Whether it will become a force for good or ill depends on man, and only if the United States occupies a position of pre-eminence can we help decide whether this new ocean will be a sea of peace or a new terrifying theatre of war. I do not say the we should or will go unprotected against the hostile misuse of space any more than we go unprotected against the hostile use of land or sea, but I do say that space can be explored and mastered without feeding the fires of war, without repeating the mistakes that man has made in extending his writ around this globe of ours.

WE SET SAIL ON THIS NEW SEA BECAUSE THERE IS NEW KNOWLEDGE TO BE GAINED, AND NEW RIGHTS TO BE WON

President Kennedy infused his speech with a clear sense of optimism and urgency while also acknowledging the risk and cost of the Apollo programme

ALAMY

There is no strife, no prejudice, no national conflict in outer space as yet. Its hazards are hostile to us all. Its conquest deserves the best of all mankind, and its opportunity for peaceful cooperation many never come again. But why, some say, the Moon? Why choose this as our goal? And they may well ask why climb the highest mountain? Why, 35 years ago, fly the Atlantic? Why does Rice play Texas?

We choose to go to the Moon. We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organise and measure the best of our energies and skills, because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one which we intend to win,

SETBACKS AND SUCCESS

Piers Bizony looks back on the significant events that led to JFK's decision to put America on the fast track to the Moon

Yuri Gagarin's spaceflight on 12 April 1961 was a major embarrassment for President John F Kennedy, the White House's new occupant. Until that point, he hadn't taken the space race seriously, and he was alarmed at the global response to Russia's triumph. He paced the White House asking his advisors, "What can we do? How can we catch up?"

Just one week later, Kennedy suffered another defeat. A 1,300-strong force of exiled Cubans, supported by the CIA, landed at the Bay of Pigs in Cuba with the intention of destroying Fidel Castro's regime. Kennedy had approved the invasion, but Castro's troops knew what was coming and were waiting on the beaches. The raid was a complete disaster.

There was some encouragement for the new president, however. On 5 May 1961, NASA astronaut Alan Shepard was launched atop a small Redstone booster. His flight wasn't a full orbit of Earth, merely a ballistic arc lasting approximately 15 minutes. Gagarin's Vostok craft had circled the world, while Shepard's little Mercury capsule splashed into the Atlantic just a few hundred kilometres from its launch site. But it was enough to prove NASA's capabilities.

Kennedy now turned to space as a means of bolstering his credibility. On 25 May 1961, he made his landmark address to Congress pledging America to a Moon landing "before this decade is out" and the Apollo project was born. The popular assumption is that Russia never came near to landing men on the Moon. But since the fall of the Soviet empire in 1989, startling truths have emerged about how incredibly hard they tried to beat Apollo.

and the others, too. It is for these reasons that I regard the decision, last year, to shift our efforts in space from low to high gear as among the most important decisions that will be made during my incumbency in the office of the Presidency.

In the last 24 hours we have seen facilities now being created for the greatest and most complex exploration in man's history. We have felt the ground shake and the air shattered by the testing of a Saturn C-1 booster rocket, many times as powerful as the Atlas, which launched John Glenn, generating power equivalent to 10,000 automobiles with their accelerators on the floor. We have seen the site where the F-1 rocket engines, each one as powerful as all eight engines of the Saturn C-1 combined, will be clustered together to make the advanced Saturn V missile, assembled in a new building to be built at Cape Canaveral as tall as a 48-storey structure, as wide as a city block and as long as two lengths of this field.

Within these last 19 months at least 45 satellites have circled the Earth. Some 40 of them were 'made in the United States of America' and they were far more sophisticated and supplied far more knowledge to the people of the world than those of the Soviet Union.

The Mariner spacecraft now on its way to Venus is the most intricate instrument in the history of space science. The accuracy of that shot is comparable to firing a missile from Cape Canaveral and dropping it in this stadium between the 40-yard lines.

Transit satellites are helping our ships at sea to steer a safer course. TIROS [Television Infrared Observation] satellites have given us unprecedented warnings of hurricanes and storms, and will do the same for forest fires and icebergs.

We have had our failures, but so have others, even if they do not admit them. And they may be less public.

To be sure, we are behind, and will be behind for some time in manned flight. But we do not intend to stay behind, and in this decade, we shall make up and move ahead.

The growth of our science and education will be enriched by new knowledge of our Universe and environment, by new techniques of learning and mapping and observation, by new tools and computers for industry, medicine, the home as well as the school. Technical institutions, such as Rice, will reap the harvest of these gains.

And finally, the space effort itself, while still in its infancy, has already created a great number of new companies, and tens of thousands of new jobs. Space and related industries are generating new demands in investment and skilled personnel, and this city and this state, and this region, will share greatly in this growth. What was once the furthest outpost on the old frontier of the West will be the furthest outpost on the new frontier of science and space. Houston, your city of Houston, with its Manned Spacecraft Center, will become the heart of a large scientific and engineering community. During the next five years the National Aeronautics and Space Administration expects to double the number of scientists and engineers in this area, to increase its outlays for salaries and expenses to $60 million a year; to invest some $200 million in plant and laboratory facilities; and to direct or contract for new space efforts over $1 billion from this Center in this city.

To be sure, all this costs us all a good deal of money. This year's space budget is three times what it was in January 1961, and it is greater than the space budget of the previous eight years combined. That budget now stands at $5,400 million a year – a staggering sum, though

PRIVILEGE AND PUBLIC SERVICE

John Fitzgerald Kennedy was born in Massachusetts on 29 May 1917, into one of America's richest and most influential families. He had a charmed upbringing and graduated from Harvard in 1940 before serving in the US Naval Reserve during the Second World War.

After leaving the military, he rose quickly through the political ranks and ran as the Democratic candidate in the 1960 presidential election. His successful campaign, managed by his younger brother Robert Francis Kennedy, saw him become the 35th US President and enter the White House aged just 43.

The civil rights movement along with the escalating tensions in Vietnam and the Cold War made JFK's first two years in the White House extremely turbulent. After narrowly avoiding a nuclear conflict as a result of 1962's Cuban Missile Crisis, he successfully negotiated the Limited Nuclear Test Ban treaty in 1963, which the US, USSR and Great Britain agreed to sign.

Controversy surrounded JFK's private life, however, and he's believed to have conducted a string of extramarital affairs before and during his term in office, with a list of women said to include Marilyn Monroe and Marlene Dietrich. But the greatest tragedy came on 22 November 1963 when JFK was assassinated during a visit to Dallas, Texas. Although the killing was attributed to Lee Harvey Oswald (himself killed days later by Jack Ruby), many believe Kennedy's assassination to have been the result of a conspiracy.

Dr Wernher von Braun (centre) of NASA discusses the Saturn launch system with President John F Kennedy

WE HAVE HAD OUR FAILURES, BUT SO HAVE OTHERS, EVEN IF THEY DO NOT ADMIT THEM

somewhat less than we pay for cigarettes and cigars every year. Space expenditures will soon rise some more, from 40 cents per person per week to more than 50 cents a week for every man, woman and child in the United States, for we have given this programme a high national priority – even though I realise that this is in some measure an act of faith and vision, for we do not now know what benefits await us.

But if I were to say, my fellow citizens, that we shall send to the Moon, 240,000 miles away from the control station in Houston, a giant rocket more than 300-feet tall – the length of this football field – made of new metal alloys, some of which have not yet been invented, capable of standing heat and stresses several times more than have ever been experienced, fitted together with a precision better than the finest watch, carrying all the equipment needed for propulsion, guidance, control, communications, food and survival, on an untried mission, to an unknown celestial body, and then return it safely to Earth, re-entering the atmosphere at speeds of over 25,000 miles per hour, causing heat about half that of the temperature of the Sun – almost as hot as it is here today – and do all this, and do it right, and do it first before this decade is out – then we must be bold.

I'm the one who is doing all the work, so we just want you to stay cool for a minute. [Laughter]

However, I think we're going to do it, and I think that we must pay what needs to be paid. I don't think we ought to waste any money, but I think we ought to do the job. And this will be done in the decade of the '60s. It may be done while some of you are still here at school at this college and university. It will be done during the term of office of some of the people who sit here on this platform. But it will be done. And it will be done before the end of this decade.

I am delighted that this university is playing a part in putting a man on the Moon as part of a great national effort of the United States of America.

Many years ago the great British explorer George Mallory, who was to die on Mount Everest, was asked why did he want to climb it. He said, "Because it is there."

Well, space is there, and we're going to climb it; and the Moon and the planets are there, and new hopes for knowledge and peace are there. And, therefore, as we set sail we ask God's blessing on the most hazardous and dangerous and greatest adventure on which man has ever embarked

Thank you. **SF**

BBC NEWS

Listen to ***The Story Behind The Man Who Shot JFK***
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NASA

ET MEN

ROCKET

Thousands of engineers, mathematicians and airmen helped send the first humans to the Moon. But only three astronauts got to make the historic voyage and were it not for one controversial rocket scientist, the whole endeavour may not have been possible

words by PIERS BIZONY

The Apollo 11 crew: (from left) Buzz Aldrin, Michael Collins and Neil Armstrong

The first man: Neil Armstrong achieved a historic feat by landing and walking on the Moon

GETTY IMAGES X2

NEIL ARMSTRONG

APOLLO 11 MISSION COMMANDER

Born in the summer of 1930 near the small town of Wapakoneta, Ohio, Neil Armstrong obtained a pilot's licence when he was just 16, before he could drive a car. He studied aeronautical engineering at Purdue University in Indiana, then, after becoming a Navy pilot, flew 78 missions during the Korean War. One sortie ended in a crash behind enemy lines, but Armstrong managed to reach safety a day later.

Leaving the Navy in 1952, he joined the National Advisory Committee on Aeronautics (NACA), the modest collection of research laboratories and air bases that, six years later, would become NASA. As a test pilot at NACA's High Speed Flight Station at Edwards Air Force Base in California, he flew various aircraft, including the X-15 rocket plane, still the fastest manned aircraft. On his flights, Armstrong reached speeds of 6,400km/h and climbed more than 63km to reach the edge of space.

Armstrong became a NASA astronaut in 1962. Because of his experiences aboard the X-15, he commanded his first flight into orbit, aboard Gemini 8, in March 1966. With co-pilot David Scott, he performed the first docking of two spacecraft by mating the Gemini

BIOGRAPHY

NEIL ARMSTRONG

b. 05.08.30 – d. 25.08.12

■ **5 AUGUST 1930**
Neil Alden Armstrong is born in Wapakoneta, Ohio to Stephen Koenig Armstrong and Viola Louise Engel.

■ **14 SEPTEMBER 1947**
Begins studies in aeronautical engineering at Purdue University, Indiana.

■ **26 JANUARY 1949**
Called up to the US Navy to begin flight training.

■ **12 AUGUST 1950**
Qualifies as a naval aviator.

■ **29 AUGUST 1951**
First action in the Korean War, escorting a photo reconnaissance mission.

■ **3 SEPTEMBER 1951**
Forced to eject after being shot down on a bombing run.

■ **JANUARY 1955**
Graduates from Purdue University with a bachelor of science degree.

■ **28 JANUARY 1956**
Marries Janet Elizabeth Shearon. The couple have three children, Eric, Karen and Mark.

■ **15 AUGUST 1957**
First flight in a rocket-propelled vehicle, the Bell X-1B, climbing to 18km.

■ **28 JANUARY 1962**
Daughter Karen dies, aged two years old, after a six-month battle with a brain tumour.

■ **20 APRIL 1962**
X-15 rocket plane bounces off the atmosphere during re-entry, causing the longest X-15 flight in time and distance.

■ **13 SEPTEMBER 1962**
Selected for astronaut training by NASA.

■ **16 MARCH 1966**
First launch into space, as commander of Gemini 8.

■ **23 DECEMBER 1968**
Selected as commander of Apollo 11.

■ **AUGUST 1971**
Resigns from NASA.

■ **1989**
Wife Janet initiates a divorce.

■ **12 JUNE 1994**
Marries his second wife, Carol Held Knight.

■ **25 AUGUST 2012**
Neil Armstrong, the first human to set foot on the Moon, dies as a result of complications associated with heart surgery.

Armstrong in the cockpit of one of the three X-15 rocket planes after a research flight. He flew the X-15 seven times

NASA/ISC X2

with an uncrewed Agena target vehicle. When it came to undocking, however, a thruster locked in the 'on' position and sent the Gemini 8 craft into a spin. Armstrong managed to avert disaster by recovering control, and in so doing got noticed by NASA's management.

His coolness under pressure seemed extraordinary. In May 1968 he was flying a Lunar Landing Research Vehicle (LLRV), a skeletal four-legged contraption balancing on the trust from a single powerful jet engine. The LLRV tipped out of control and Armstrong ejected with less than two seconds to spare before it smashed into the ground and exploded. An hour later, he was back at work in his office as though nothing had happened.

Some of Armstrong's pilot colleagues felt that he was too dry and academic to be a high-profile astronaut. NASA, however, considered him an ideal candidate for computerised systems-driven spacecraft, which needed abstract reasoning skills rather than traditional 'stick-and-rudder' heroics.

The blind luck of crew rotation secured Armstrong's place in history. Frank Borman was expected to be the mission commander for the first landing attempt, until the pressures of the Moon race with Russia required him to lead the hastily scheduled Apollo 8 circumlunar flight in December 1968.

Armstrong became deputy associate administrator for aeronautics at NASA after Apollo 11, but resigned in 1971 to become professor of aeronautical engineering at the University of Cincinnati, a post he held for the rest of his career.

Michael Collins modestly claimed that the main qualification necessary for flying to the Moon was to have been born at the right time

BBC iPlayer

*Watch Michael Collins interviewed on **Hard Talk***
bbc.in/2KVUXkO

MICHAEL COLLINS

APOLLO 11 COMMAND MODULE PILOT

Michael Collins was born in Rome in 1930, while his father was stationed there as an Army attaché. His father's military career meant the family moved frequently and, as well as Italy, Collins spent his childhood in Oklahoma, New York, Puerto Rico and Virginia.

Although Collins graduated from West Point Military Academy in 1952, an institution associated with the Army, he decided to join the Air Force instead. He flew fighters in Europe and went on to be an Air Force instructor before becoming a test pilot at Edwards Air Force Base in California in 1960. He joined NASA in 1963.

Collins was co-pilot aboard Gemini 10 in July 1966, with John Young in command, and made two spacewalks, becoming the first person ever to make more than one during a single mission.

A mix of bad luck and good fortune helped determine who would fly the historic first missions. Collins had originally been assigned to Apollo 8, but in 1968 he began to suffer from alarming incidents in which his legs would buckle for no apparent reason. The cause turned out to be trapped nerves in his spine. He underwent successful surgery to remedy the problem, which delayed his return to flight status until a later mission, which turned out to be Apollo 11.

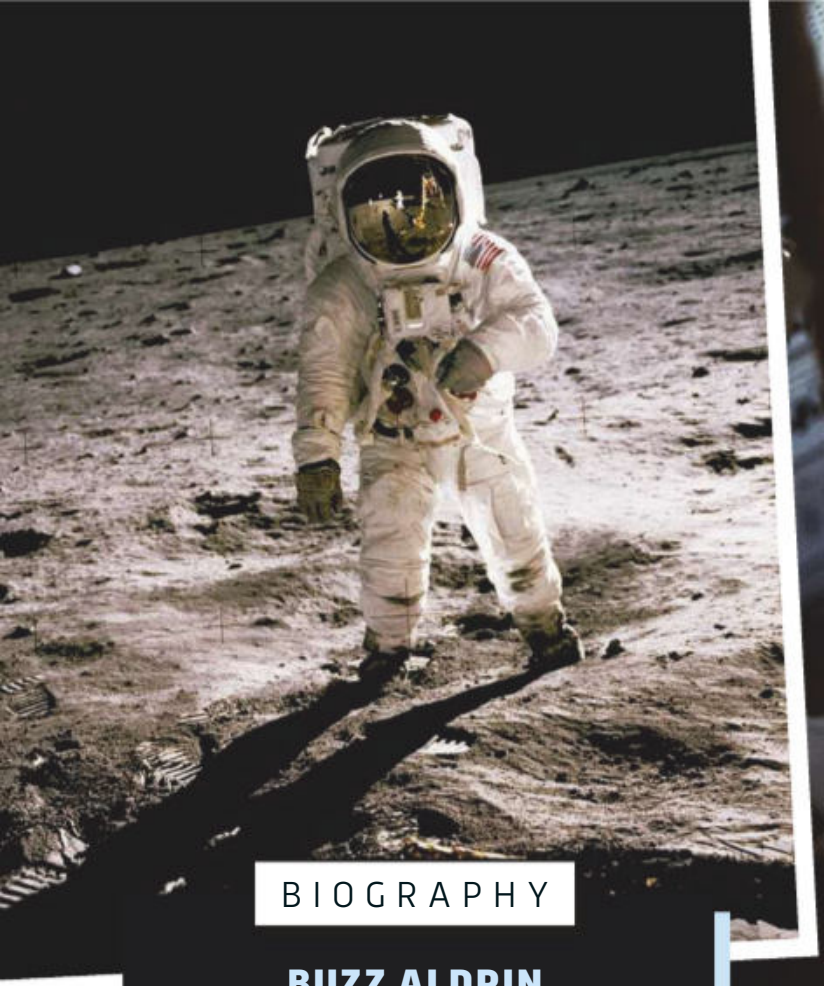
Collins's autobiography, *Carrying The Fire: An Astronaut's Journey*, first published in 1974, is a lively account of his experiences at NASA, and of flying around the Moon in support of his Apollo colleagues. A modest and thoughtful man, he once said that "...the main qualification for flying to the Moon was to have been born at the right time, 1930, give or take a year or two." He was sensitive to the charge that NASA's technical language had stripped Apollo 11 of some of its meaning, at least in the eyes of the general public. "I think a future flight should include a poet, a priest and a philosopher," he said in 1973. "Then we might get a much better idea of what we saw."

BIOGRAPHY

MICHAEL COLLINS

b. 31.10.30

- **31 OCTOBER 1930** Michael Collins is born in Rome to Major General James Lawton Collins and Virginia Stewart.
- **MAY 1952** Graduates from West Point Military Academy.
- **JUNE 1954** Transfers to Chaumont-Semoutiers Air Base, eastern France, with the US Air Force.
- **SUMMER 1956** Forced to eject over France due to a fire in his F-86 Sabre jet.
- **SUMMER 1957** Marries Patricia Finnigan. They have three children, Kate, Ann and Michael Jr.
- **AUGUST 1960** Joins the US Air Force Experimental Flight Test Pilot School.
- **FEBRUARY 1962** Decides to become an astronaut after John Glenn's orbit of the Earth.
- **OCTOBER 1963** Selected for NASA's third astronaut group on the basis of his record as a test pilot.
- **18 JULY 1966** Launches into space as pilot for Gemini 10 and conducts two spacewalks.
- **JULY 1968** A trapped nerve in Collins's upper spine requires surgery, removing him from the crew of Apollo 8.
- **16 JULY 1969** Lifts off aboard Apollo 11 as the mission's command module pilot.
- **1970** Retires from NASA and becomes Assistant Secretary of State for Public Affairs.
- **JANUARY 1971** Becomes director of the Smithsonian Institution's Air and Space Museum.
- **1974** Attends Harvard Business School.
- **1978** Retires from the Air Force with the rank of major general and becomes under-secretary of the Smithsonian Institution.
- **1980** Becomes vice-president of LTV Aerospace.
- **1985** Starts his own consultancy firm, Michael Collins Associates.



Buzz Aldrin, the second man on the Moon, remains a passionate advocate for returning to it

LEFT: Aldrin photographed by Armstrong during their moonwalk

BIOGRAPHY

BUZZ ALDRIN

b. 20.01.30

■ **20 JANUARY 1930**
Edwin Eugene Aldrin Jr is born in Montclair, New Jersey to Edwin Eugene Aldrin Sr and Marion Moon.

■ **1932**
Takes his first flight, aged two, in a Lockheed Vega piloted by his father.

■ **MAY 1951**
Graduates third in his class from US Military Academy, West Point.

■ **DECEMBER 1951**
Joins the US Air Force and serves in the Korean War. Flies 66 combat missions in F-86 Sabres, shooting down two MiG-15s.

■ **29 DECEMBER 1954**
Marries Joan Archer. They have three children – James, Janice and Andrew.

■ **1956**
Begins a three-year Air Force assignment in Bitburg, Germany, flying F-100 Super Sabres.

■ **1959**
Enrols at Massachusetts Institute of Technology for a doctorate in astronautics, which he receives just over three years later.

■ **OCTOBER 1963**
Selected by NASA for its astronaut programme. He pioneers the practice of underwater training to simulate zero gravity.

■ **11 NOVEMBER 1966**
Launches into space on the Gemini 12 mission, and sets a record for longest extra-vehicular activity.

■ **4 JANUARY 1969**
Learns of his selection for the prime crew of Apollo 11.

■ **MARCH 1972**
Retires from the Air Force due to psychological and personal problems. First marriage ends in divorce.

■ **19 DECEMBER 1975**
Marries Beverly Van Zile.

■ **10 APRIL 1978**
Second marriage ends in divorce.

■ **14 FEBRUARY 1988**
Marries Lois Driggs Cannon.

■ **AUGUST 1996**
Descends 3,500m below the surface of the North Atlantic in a submarine to the wreck of the *Titanic*.

■ **1999**
Founds the ShareSpace Foundation to promote space tourism.

BUZZ ALDRIN

APOLLO 11 LUNAR MODULE PILOT

The second man on the Moon was born in 1930 in Montclair, New Jersey. His father, Edwin Eugene Sr, had been a student of the rocket pioneer Robert Goddard and became a senior figure in military aviation. He expected his son to follow in his footsteps. Aldrin complied, attending West Point Military Academy, graduating in the top three of his class, then joining the Air Force. He flew 66 combat missions in Korea and in 1963 completed a doctorate in astronautics at the Massachusetts Institute of Technology.

His doctoral thesis, 'Line-of-Sight Guidance Techniques for Manned Orbital Rendezvous', caused a sensation in the aerospace community: he had trained himself as an expert in orbital rendezvous, a crucial skill for the emerging space programme. Joining NASA in 1963, he flew aboard Gemini 12 with Jim Lovell in command and made three spacewalks, using handrails on the flanks of the Agena 12 craft (an addition that came from an idea of Aldrin's).

When Aldrin learned of his selection for Apollo 11, he assumed that Armstrong, as mission commander, would stay aboard the lunar module while he would be the first to exit and step out on to the Moon's surface. This had been the custom for all the extravehicular activity during the Gemini missions. But the design of the lunar module's interior and position of the spacecraft's door meant Armstrong had to exit first.

Aldrin's career in the wake of Apollo 11 was uneven. Returning to duty with the Air Force in 1971, he was given command of the Edwards Air Force Base, but became restless and unhappy. Another issue for Aldrin was his unrewarding relationship with his father – an ungenerous, hard-driving man who seldom gave his son any credit for his achievements.

He suffered from the anticlimax of returning to normality. In 1973 he said, "I had been to the Moon. What could I possibly do next? I suffered from what the poets have described as 'the melancholy of all things done'."

NASA/ISC X3

WERNHER VON BRAUN

DIRECTOR OF THE MARSHALL SPACE FLIGHT CENTER/SATURN V CHIEF ARCHITECT

Wernher von Braun was a pivotal, if controversial, figure in the space race. Born to an aristocratic family in the Prussian town of Wirsitz (now in Poland) in 1912, he was inspired in his teens by the work of German physicist Hermann Oberth, and became a rocket scientist.

Earning his doctorate in rocket combustion in 1934, the year after Hitler came to power in his homeland, he joined the Nazi party and became technical director of the German rocket programme. By 1942 he had successfully developed the infamous V-2 rocket that was to wreak such havoc on London during the Blitz. Equally notorious was the programme's use of slave labour – an uncomfortable legacy that would stay with von Braun for the rest of his life.

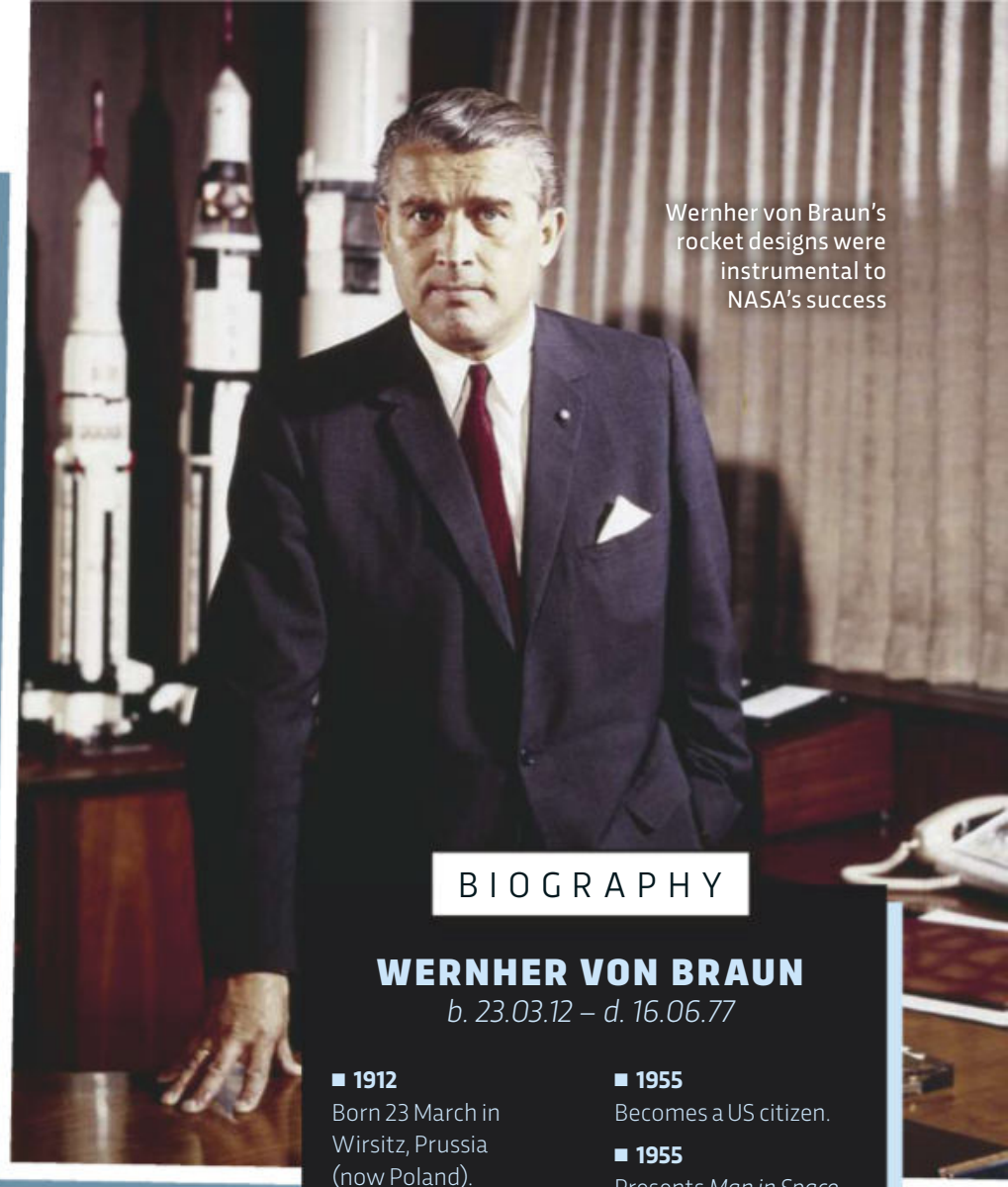
Instead of being tried as war criminals, however, von Braun and his team were secretly whisked away to the US after the war and recruited to the American rocket programme as part of Operation Paperclip. The scientists saw defecting to the US as their best option for continuing their work. Germany was in ruins, the UK's rocket programme was in its infancy and the whole team feared its fate at the hands of the Russians. After demonstrating the V-2 rocket to the US army, von Braun became technical director of the Guided Missile Development Group at Redstone Arsenal, Alabama, in 1950.

The public perception of von Braun was changed somewhat after a surreal offer from Walt Disney in 1954. Keen to promote his new Disneyland theme park, Walt turned to von Braun to host *Man in Space* – TV infomercials publicising the park's fantasy theme. He became a space evangelist, preaching to an audience of 42 million viewers.

In 1960, von Braun became the first director of NASA's Marshall Space Center and found himself centre stage in the space race. He never met Sergei Korolev, his Russian rival in this Cold War face-off and it was no coincidence that with Korolev's death in 1966, the Soviet challenge effectively evaporated. Von Braun's rockets were at the heart of the Mercury, Gemini and Apollo space programmes, not least the Saturn boosters that propelled man to a first Moon landing in 1969. Indeed, had von Braun not insisted on additional tests for safety, Alan Shepard's Freedom 7 would have beaten Yuri Gagarin's Vostok 1 into space by three weeks in 1961.

America's enthusiasm for the space programme cooled after the Moon landing, and von Braun died a frustrated man in 1977, still dreaming of missions to Mars. Had he lived, worse would have followed, as documents about his Nazi past were declassified in 1984. His life remains highly controversial but his mind was unquestionably brilliant. **SF**

by **PIERS BIZONY** *(@PiersBizony)*
Piers is a science journalist and space historian. His latest book is ***Moonshots: 50 Years Of NASA Space Exploration Seen Through Hasselblad Cameras***



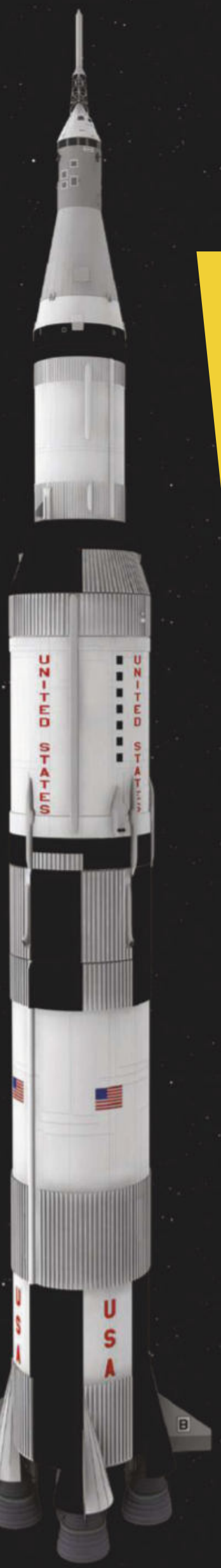
Wernher von Braun's rocket designs were instrumental to NASA's success

BIOGRAPHY

WERNHER VON BRAUN

b. 23.03.12 – d. 16.06.77

- **1912** Born 23 March in Wirsitz, Prussia (now Poland).
- **1925** Inspired by Hermann Oberth to pursue rocketry.
- **1934** Graduates from Berlin Technical University.
- **1937** Becomes technical director of rocket research facility at Peenemünde.
- **1937** Joins the Nazi party.
- **1940** Joins the SS.
- **1943** Slave labour introduced at Peenemünde to produce V-2.
- **1944** Arrested by Gestapo as a 'communist sympathiser'; released on Hitler's orders.
- **1945** Surrendered to American forces and secreted to the US.
- **1947** Returns to Germany to marry his cousin, Maria Louise von Quistorp.
- **1950** Begins developing Redstone rocket.
- **1955** Becomes a US citizen.
- **1955** Presents *Man in Space* on US TV to promote Disneyland.
- **1958** Launches the West's first satellite, Explorer 1, with modified Redstone rocket.
- **1960** Becomes director of the Marshall Space Flight Center.
- **1960-69** Develops Saturn rocket for Apollo programme.
- **1969** Expresses optimism that Saturn V could be developed for a Mars mission.
- **1970** Appointed NASA's Deputy Associate Administrator for Planning.
- **1972** Retires from NASA.
- **1973** Diagnosed with kidney cancer.
- **1975** Becomes president of National Space Institute.
- **16 JUNE 1977** Dies of pancreatic cancer, aged 65.



The Apollo 11 spacecraft lifts off aboard the gigantic Saturn V rocket on 16 July to start its journey to the Moon

SATURN V

TALLER, HEAVIER AND MORE POWERFUL THAN ANYTHING THAT HAD COME BEFORE, THE ROCKET THAT BLASTED THE APOLLO 11 CREW TOWARDS THE MOON WAS A BEHEMOTH. BUT ONLY A TINY PROPORTION OF IT WOULD ACTUALLY BE MAKING THE FULL ROUND-TRIP

words by PETER BOND

Mankind's greatest adventure, the first mission to land on the Moon, began at Cape Kennedy, Florida, at 9.32am on 16 July 1969. The ground shook as the giant Saturn V rocket slowly rose into the blue morning sky. It was only the fourth time that the booster had blasted off with a crew on board.

Saturn V flew a total of 13 times between 1967 and 1973 with a 100 per cent success record. Designed and developed at NASA's Marshall Space Flight Center in Huntsville, Alabama, under German rocket pioneer Wernher von Braun, it was the most powerful rocket ever built: a huge, three-stage leviathan, weighing more than 3,000 tonnes and towering 110m above the launch pad. Inside were some 12 million working parts, which caused von Braun to say: "I find myself thinking of all those many parts – all built by the lowest bidder – and I pray that everyone has done his homework." We look at some of the most important parts here…

BBC TWO

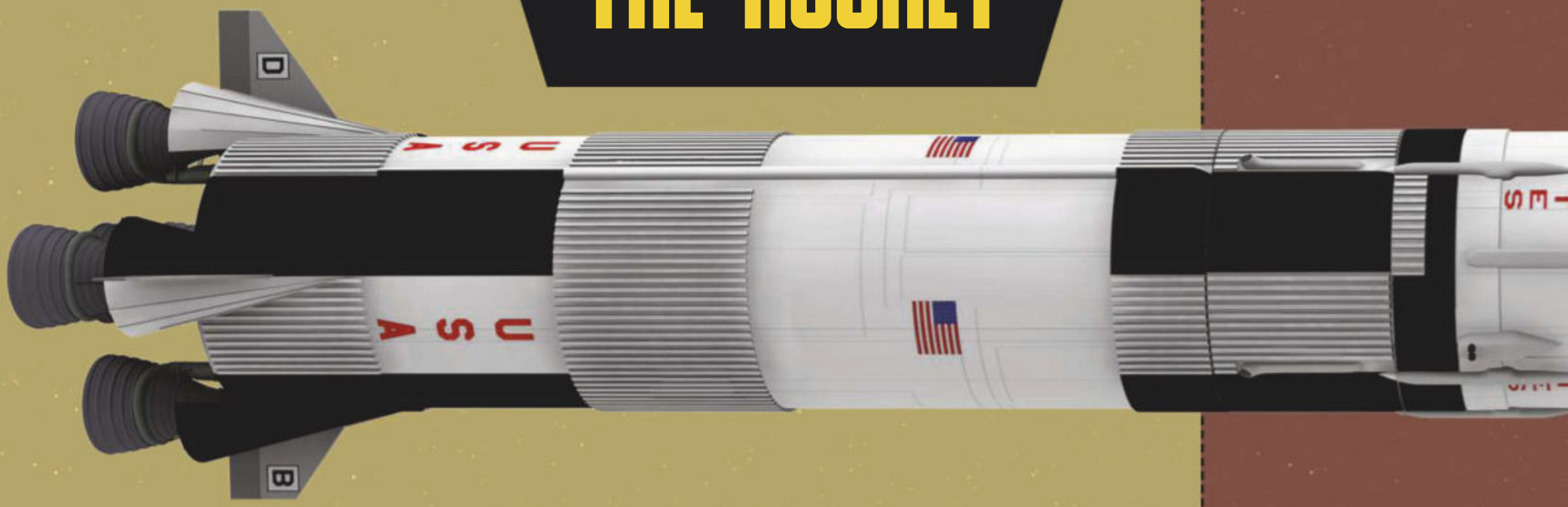
*Take a brief tour of the Saturn V rocket – **James May On The Moon***
bbc.in/2W6mRvS

GETTY IMAGES

THE ROCKET

STAGE ONE *(S-IC)*

STAGE TWO *(S-II)*



STAGE ONE *(S-IC)*

Measuring 42m high and 10m wide, the Saturn V's first stage, known as S-IC, on its own was larger than any single previous rocket. Even without its propellant, the stage weighed 139,300kg. Fully loaded with liquid oxygen and a refined kerosene, otherwise known as Rocket Propellant-1, it topped the scales at 213,566kg, almost 215 tonnes.

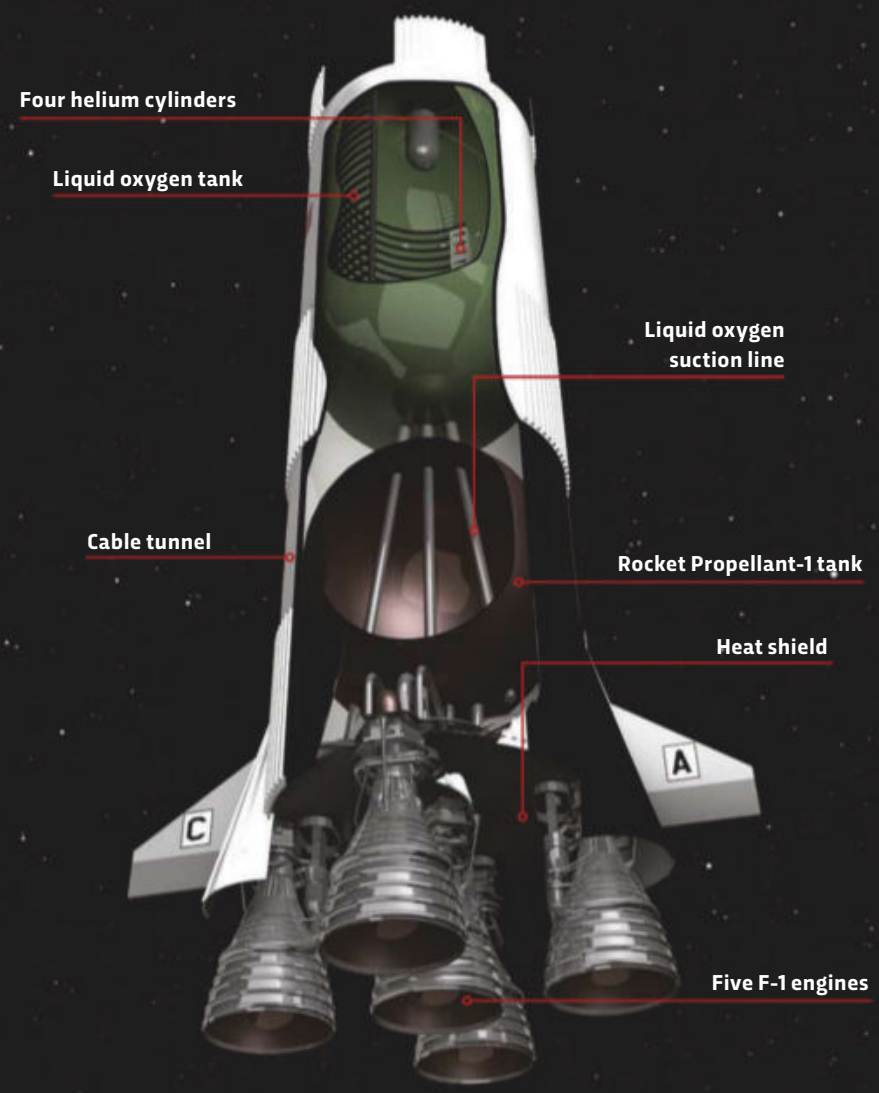
To lift the massive rocket off the ground, stage one's five F-1 engines, designed by American rocket engine manufacturer Rocketdyne, had to consume about 15 tonnes of fuel each second and generate 3.4 million kilograms of thrust. They burned for two-and-a-half minutes, boosting Saturn V to an altitude of 66km and reaching a top speed of 9,840km/h.

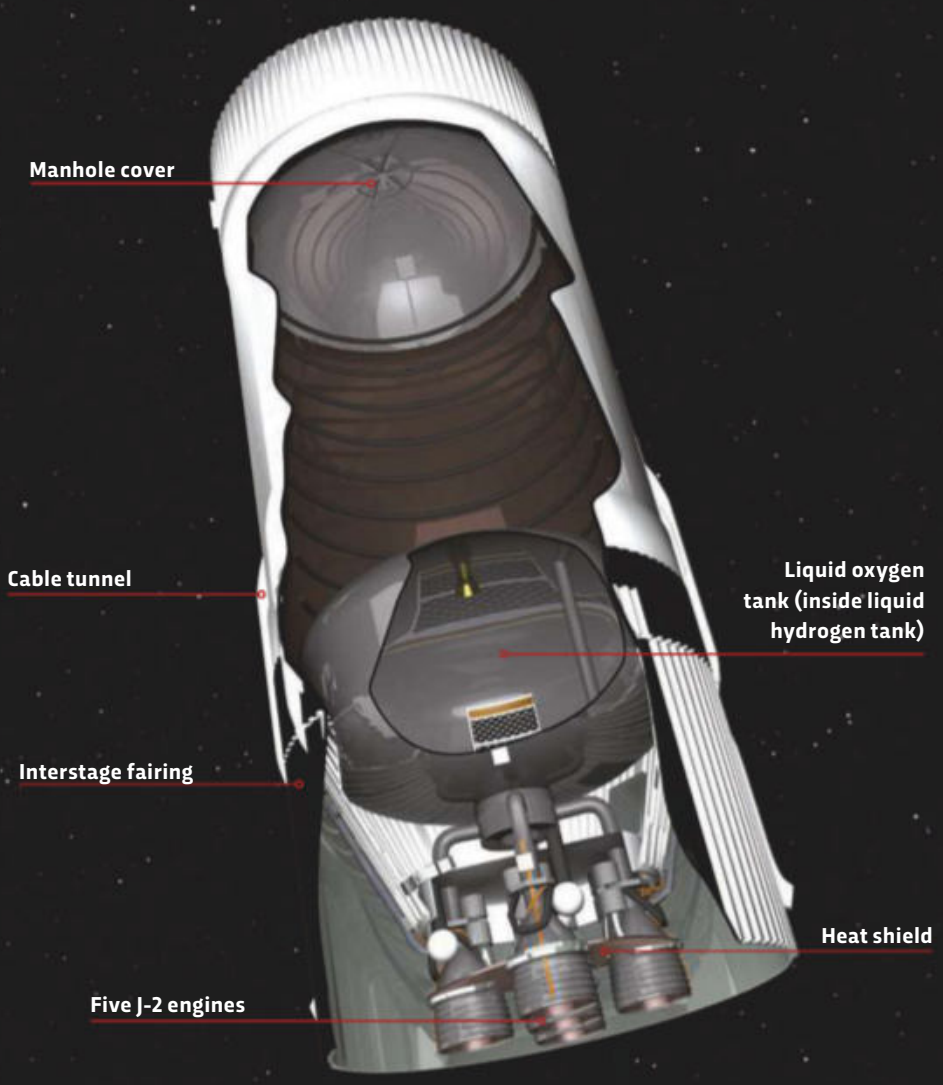
STAGE TWO *(S-II)*

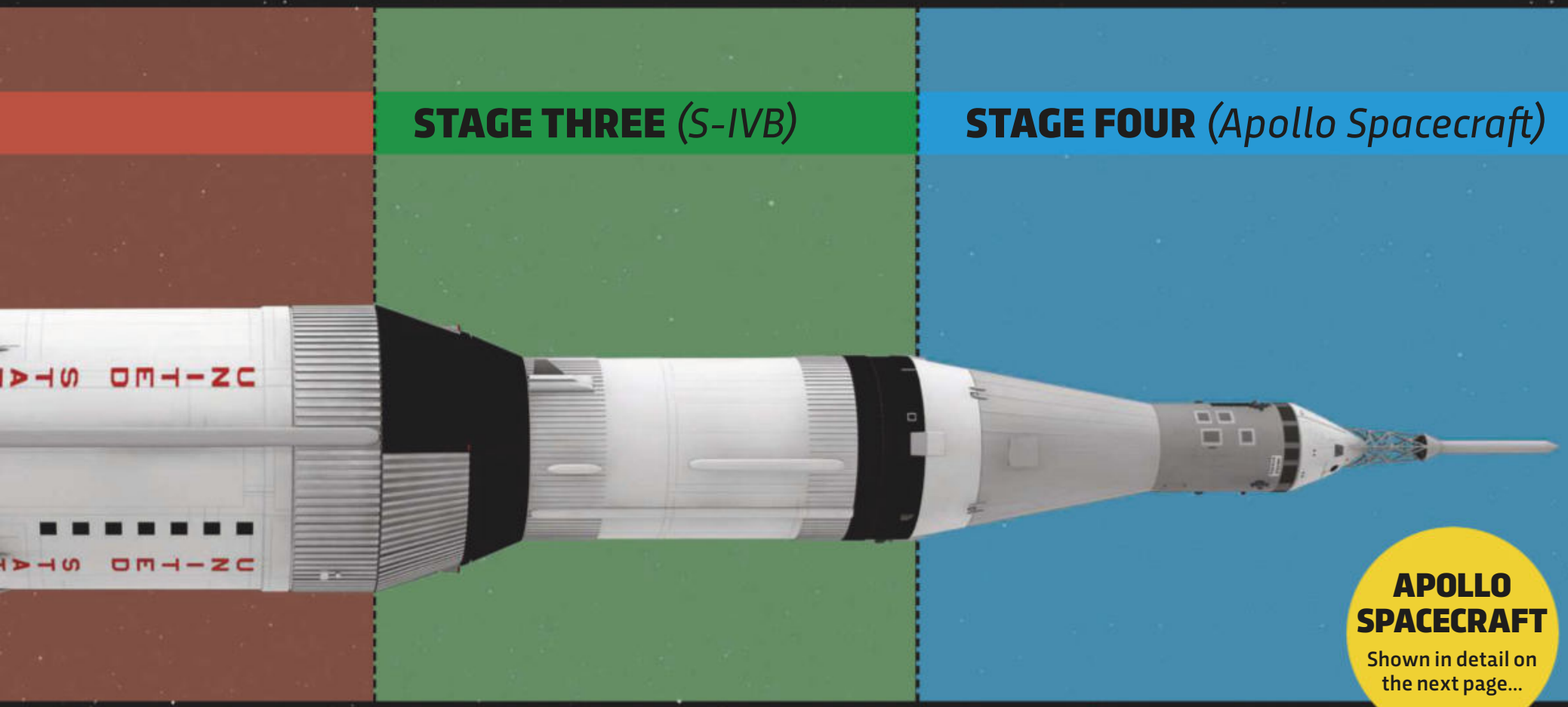
After the F-1 engines shut down, the first stage was jettisoned, allowing the five J-2 engines of S-II, the second stage, to start their burn.

About three minutes after launch, the interstage fairing between stage one and two was also cast off, followed by the launch escape tower on the tip of stage four, as the rocket accelerated to 24,625km/h.

The J-2 engines, also developed by Rocketdyne, burned a mixture of supercooled liquid oxygen and liquid hydrogen. About nine minutes after lift-off, as the engines shut down, the Saturn V would have reached an altitude of 185km. By now the rocket was flying east over the mid-Atlantic and was already more than 1,600km away from the launch site.





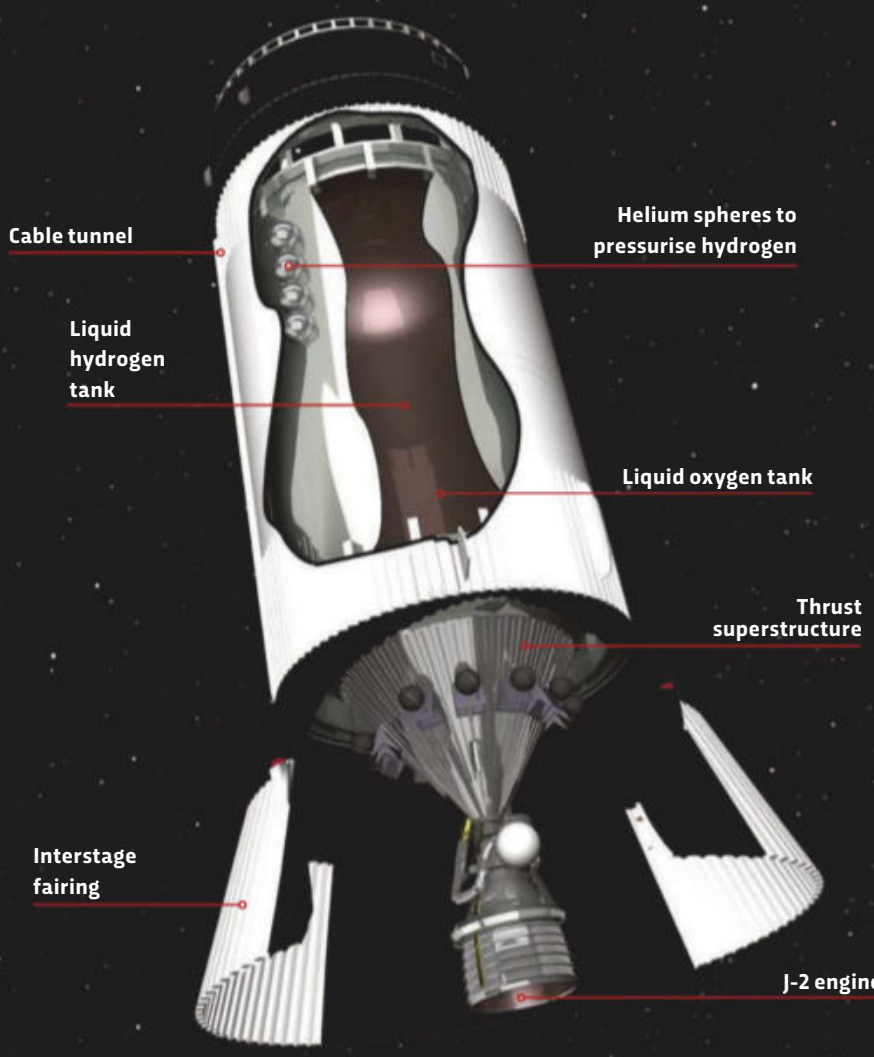


STAGE THREE *(S-IVB)*

Once the second stage had finished its burn, the third stage completed the journey to Earth orbit. This stage, S-IVB, was powered by a single, restartable J-2 engine, providing a maximum thrust of 104,325kg. The engine first fired for two and a half minutes, to increase the speed to 28,000km/h, enabling the spacecraft to enter an Earth parking orbit at an average height of 160km.

After a two-and-a-half-hour checkout period, when the spacecraft was halfway around its second orbit, the J-2 engine was fired again, for a burn that lasted five minutes and 20 seconds, to start the journey towards the Moon.

Once stage three had separated from the Apollo spacecraft (stage four), its engine fired for a third and final time to send it into orbit around the Sun.

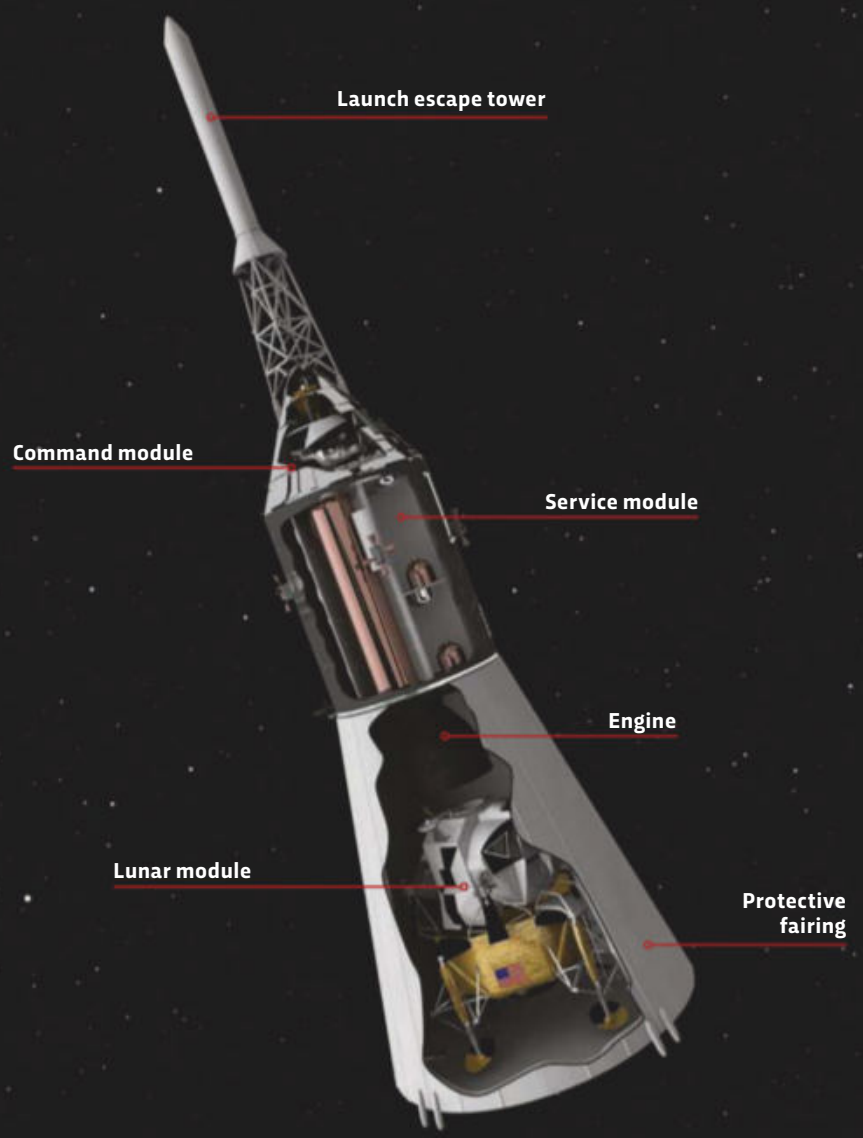


STAGE FOUR *(Apollo Spacecraft)*

On top of the Saturn V was the Apollo spacecraft, which would carry the three-man crew to the Moon, land two of them on the surface and then return them all to Earth.

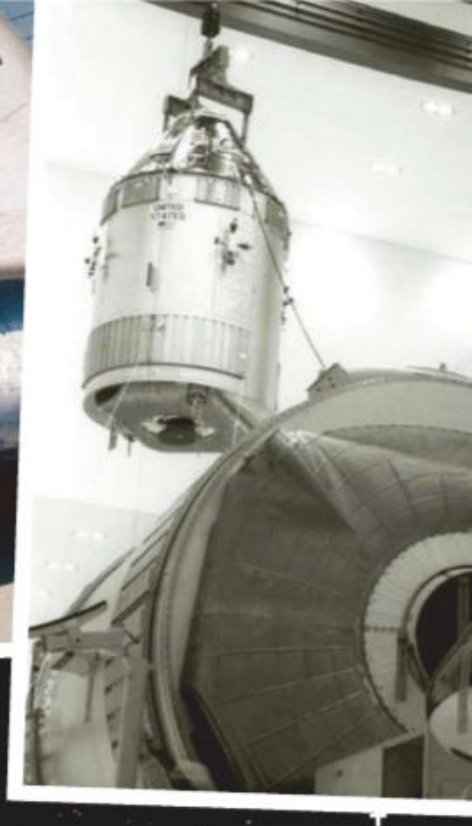
Stashed inside the protective fairing was the lunar module (both its descent and ascent stages), while perched on top of it were the command and service modules (CSM).

Once the flight to the Moon was underway, the fairing around the lunar module was released. The CSM then pulled away from the lunar module, rotated 180° and edged back towards it. Once the two spacecraft were docked, and the astronauts were able to access the lunar module, they were ready for a three-day trip to the Moon – the translunar coast.



ILLUSTRATIONS: PAUL WOOTTON

THE APOLLO SPACECRAFT

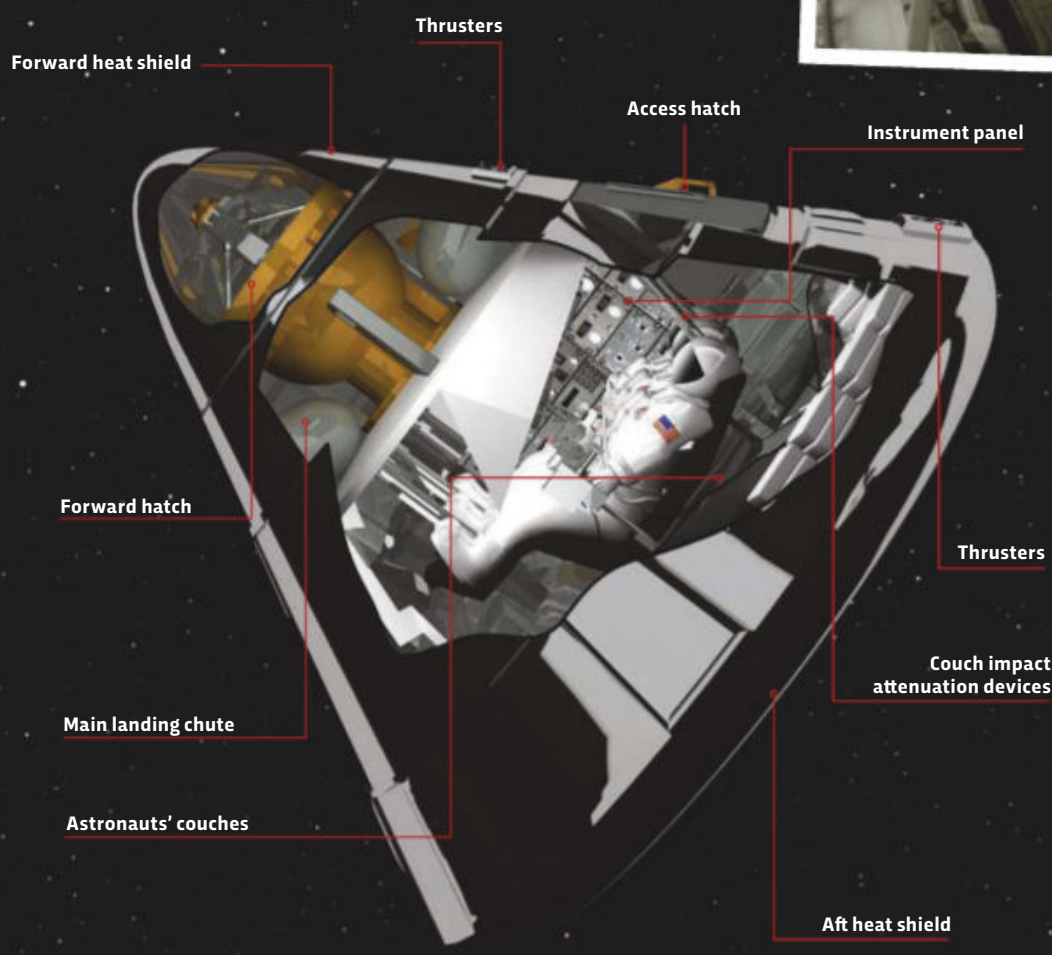


COMMAND MODULE (Columbia)

The cone-shaped command module was the astronauts' home for the eight-day mission. At its centre were three contoured couches for the astronauts that had been specially designed to reduce the effect of the g-forces generated during launch and re-entry. Arrayed around these were instrument panels, navigation gear, radios and life-support systems.

Built for NASA by North American Aviation, the command module had a launch weight of 5,570kg, was 3.5m high and had a maximum diameter of 3.9m. The main crew access hatch was at the side, with another hatch and docking probe located in the nose.

The command module came back to Earth base first, protected by a heat shield; small thrusters were fired to keep it stable during re-entry. Three parachutes deployed during the final stages of the descent to cushion the splashdown in the Pacific Ocean.



SERVICE MODULE

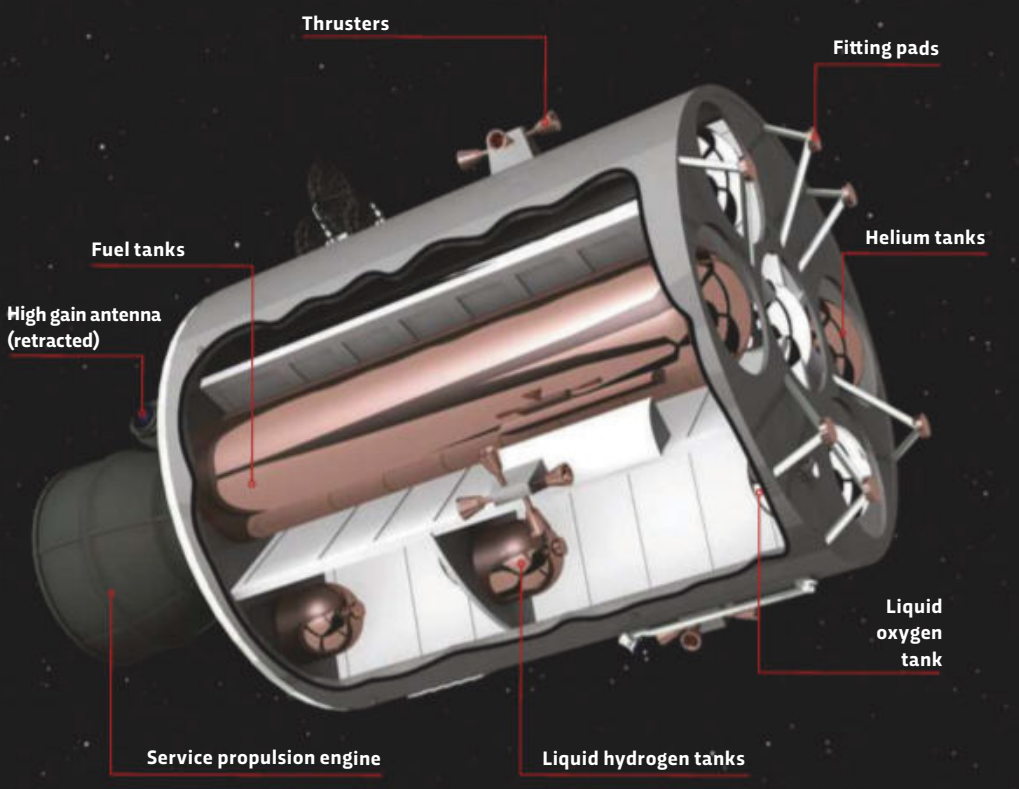
The cylindrical service module was attached to the base of the command module right up until the spacecraft arrived back at Earth for re-entry.

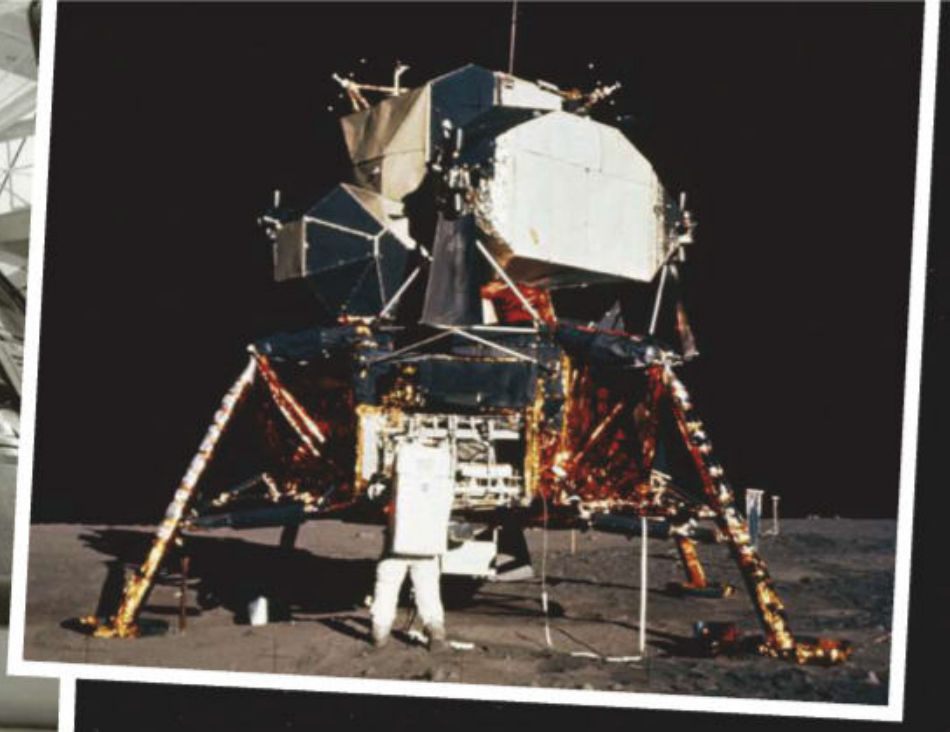
Also built by North American Aviation, the service module housed most of the life-support systems needed to operate the command module on the way to and from the Moon. These included the crew's oxygen supply and fuel cells to generate electricity, as well as tanks containing liquid hydrogen and oxygen for the fuel cells.

Small thrusters controlled the service module's movement, while one large engine was fired to brake Apollo into lunar orbit and boost it back to Earth.

The cylinder was divided into six wedge-shaped segments around the main engine, four of which housed the propellant tanks. The propellants themselves were self-igniting.

Once back near Earth, the service module separated from the command module and burnt up as it re-entered Earth's atmosphere on a separate trajectory.





FROM LEFT TO RIGHT:
The Apollo 11 crew used the Gulf of Mexico to train for their splashdown

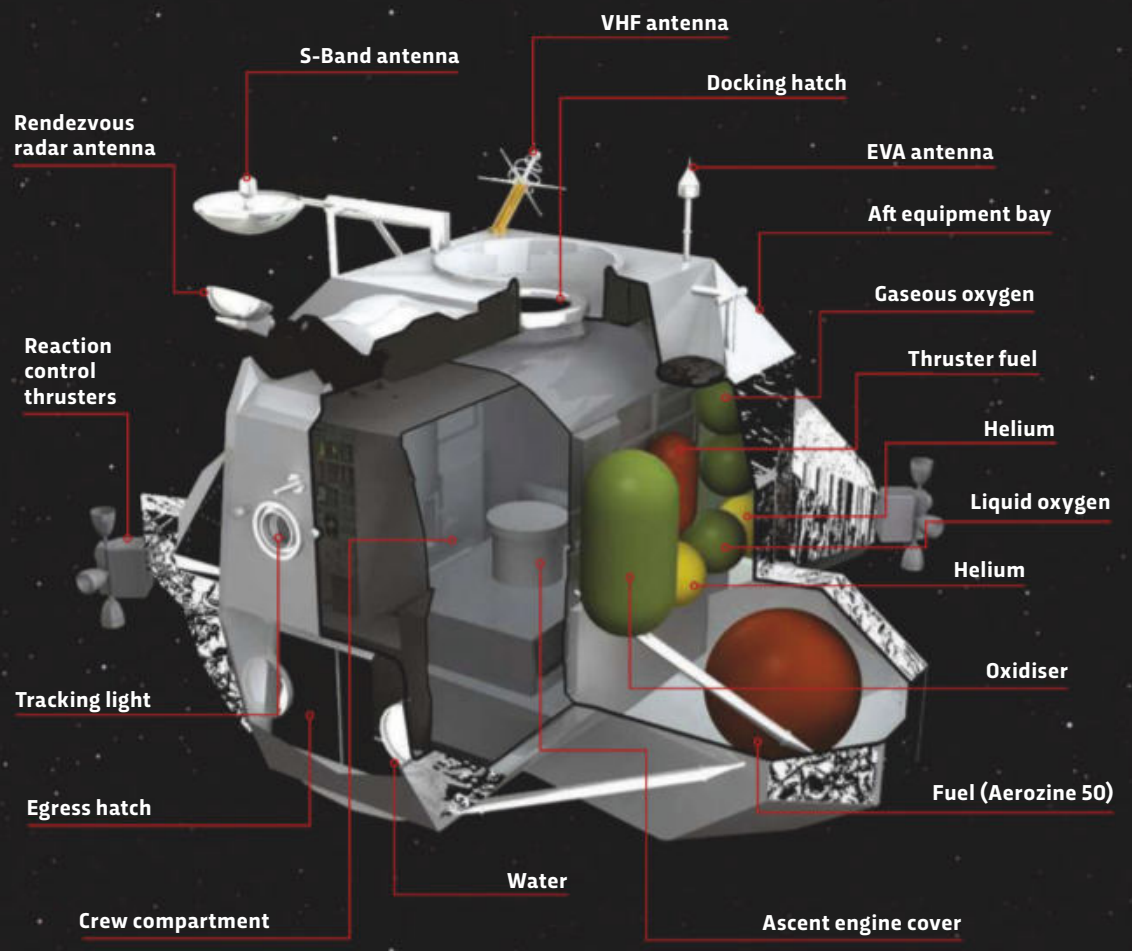
The service and command modules go through their final preparation prior to launch

Buzz Aldrin unloads the science experiments from the lunar lander

LUNAR MODULE ASCENT STAGE

The lunar module, built by Grumman, stood about 7m high, measured 4.3m in diameter and would carry Neil Armstrong and Buzz Aldrin to and from the lunar surface. The crew quarters in the ascent stage included life-support systems, communications, navigation equipment and storage bays. Controls and displays for the main engine and thrusters were duplicated, allowing either crewmember to fly the craft. During the landing, Armstrong and Aldrin stood side by side, restrained by harnesses.

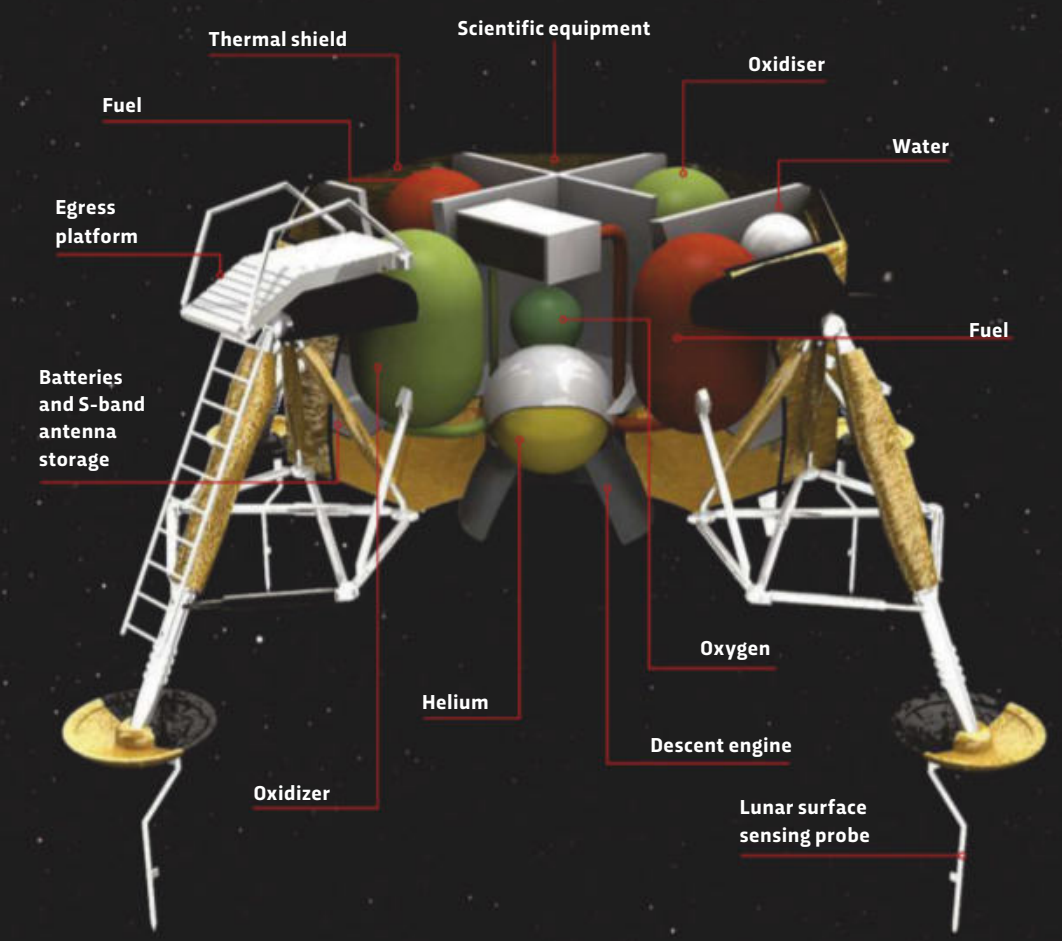
There were few luxuries and limited space inside: during their sleep period they had to lie on the cabin floor between boxes of rock samples and the engine cover. Once their brief stay came to an end, they fired the ascent engine to rendezvous with Michael Collins in lunar orbit aboard the command service module. The ascent stage was then jettisoned on the return journey.



LUNAR MODULE DESCENT STAGE

The lunar module's descent stage was essentially a landing platform weighing 10,334kg. At its centre was a single rocket engine that was used to slow the lunar module during its descent to the Moon's surface and enabled it to hover while the crew searched for a landing site.

Around this were bays containing fuel tanks, water and oxygen supplies, and storage space. Extending from the four corners were legs fitted with circular footpads and shock absorbers to cushion the landing. A 1.7m-long probe dangled beneath three of the footpads, which triggered a light in the cabin on contact with the ground. A ladder was fitted to one leg for Armstrong and Aldrin to make a careful descent to the dusty surface. The descent stage remains on the Moon to this day.



by PETER BOND
Peter is a space and astronomy writer and Fellow of the Royal Astronomical Society

Anne McClain (centre) was supposed to have joined Christina Koch (left) for the first all-female spacewalk in March 2019, but due to the lack of a suitably sized spacesuit, had to handover to Nick Hague (right)

NASA

LADIES WHO LAUNCH

To date, only 12 people have set foot on the Moon. All of them have been men and all of them have been celebrated. But none of them could have got there without the efforts and expertise of women. Women whose vital contributions to the space programme have earned nothing like the same level of recognition

words by SUE NELSON

First impressions count and few are better than the boot print Neil Armstrong made when he stepped on to lunar surface in 1969. His words – "one small step for a man, one giant leap for mankind" – also had an impact. Although it's unlikely that such gendered language would be used today, at the time they reflected a different era and a simple truth: it was a man's world.

Fifty years later, as humanity prepares to return to the Moon, people might be forgiven for thinking that not much has changed. A few months ago, after much advance publicity from NASA, a man took part in what was intended to be the first scheduled all-women spacewalk. The decision to replace Anne McClain by her male colleague, however, was based on practicalities and made by McClain herself.

Like many astronauts on board the International Space Station (ISS), McClain's height had changed. Because the fluid between vertebrae expands in microgravity, she had grown by approximately 5cm. A snug medium-sized spacesuit was now the best fit yet only one of two medium suits was primed and ready. Since every minute of an astronaut's time is accounted for, McClain's spacewalk was rescheduled. But it was an embarrassing own goal. Instead of celebrating another 'first' for women in space, it brought renewed attention on how the default size – even in space – is usually male and large.

VITAL WORK, UNRECOGNISED WORKERS

Back in 1969 such assumptions were understandable. Despite their presence throughout the Apollo programme, women in the space industry were not – as is often the case today – celebrated. It's only recently, for instance, that people learnt the identity of the sole woman pictured inside the Launch Control Center at Cape Kennedy for the Apollo 11 mission. It was JoAnn Morgan.

Morgan was an instrumentation controller and engineer. Before that, she worked to protect guidance systems from electronic interference – Morgan had to thwart the efforts of Russians aboard nearby trawlers trying to meddle with the launches of Apollo 8, 9 and 10. Not everyone appreciated her position. Occasionally, during her duties, she received obscene calls on her console phone. Since there were no women's toilets, she had to either wait for a security guard to empty the men's room or walk to a different building.

The latter scenario will be familiar to readers of Margot Lee Shetterly's book, *Hidden Figures*,

NASA/JSC, SHUTTERSTOCK

ABOVE LEFT: JoAnn Morgan (centre) was the only female engineer on hand for the Apollo 11 launch

LEFT: The film, and book, *Hidden Figures* uncovers the story of the African-American female mathematicians who played a key role in NASA's space programme

IT'S ONLY RECENTLY THAT WE LEARNT THE IDENTITY OF THE SOLE WOMAN IN LAUNCH CONTROL

or the film of the same name. It focuses on the group of women 'computers' at Langley Research Center in Virginia who, in 1962, played a role in sending astronaut John Glenn into space.

Unlike Morgan, who is white, the women featured were African American and, due to the colour of their skin, experienced far more than sexism. Apart from segregated restrooms in different buildings, they were initially expected to eat at a separate table for 'colored computers'.

The contributions of engineer Dorothy Vaughan and mathematicians Mary Jackson and Katherine Johnson, whose orbital calculations were also used in the earlier Apollo missions and helped get Armstrong and his crew to the Moon, are now more widely known. As is Margaret Hamilton, lead computer programmer of a team at the MIT Instrumentation Laboratory, whose software was vital for the Moon landings and was later adapted for Skylab and the Space Shuttle. In 2017 Hamilton was part of Lego's best-selling 'Women of NASA' set, which recreated a photograph of her standing alongside stacked volumes of Apollo navigational software.

In fact, women in a range of roles helped put the first people on the Moon. Electrical engineer Judith Love Cohen, for instance, helped

design the Abort Guidance System computer on Apollo 11's lunar module and its software. Cohen graduated as an engineer at the University of Southern California (USC) and continued studying there for further qualifications while working. "She always said that she never saw another woman engineering student during her time there from 1952 to 1962," recalls Neil Siegel, IBM Professor of Engineering Management at the USC School of Engineering and Cohen's son.

Cohen was only the eighth woman to graduate from USC as an engineer. "She had a full-time day job as an engineering associate and then as an engineer during these years, in addition to having the first three of her four children, and so mostly attended night classes," says Siegel. "So perhaps it's not surprising that she never saw another woman engineering student. She also told me that the engineering buildings did not have women's bathrooms."

THANKFULLY SHE DIDN'T GIVE UP SINCE COHEN'S WORK HELPED SAVE THE CREW OF APOLLO 13

SAFE RETURN

Like many of the pioneering women in the space industry, Cohen encountered resistance. Early on in her career, reviewing missile systems, a male colleague repeatedly told her that she was 'a girl scout trying to earn a merit badge at their expense.' Thankfully she didn't give up since Cohen's work helped save the crew of Apollo 13. When its service module was damaged by an explosion on its way to the Moon, there was a near total failure of power in the command module.

"The crew had to move to the lunar module for the rest of the mission, to stay warm," says Siegel. "But the lunar module was only designed to hold two people, not three, and wasn't designed to be powered on for several days – the time it would take to effect the return to Earth."

The computer for in-flight navigation in the command module had to be turned off but fortunately there was a computer inside the lunar module for its own navigation if, for any reason, the landing had to be stopped: Cohen's Abort Guidance System.

"This Abort Guidance System computer was re-purposed to perform the guidance needed to navigate the command module back to Earth," explains Siegel. "She also participated on the orbitology team that designed the return-to-Earth orbit, and convinced NASA – against their initial desires – to incorporate this orbit design into the design for the mission," he adds. "Without the return-to-Earth orbit design, the Apollo 13 astronauts could not have gotten home."

DRESSED FOR SUCCESS

Women's work during the Apollo programme also included more traditional jobs for the time. Dee O'Hara, for instance, was the astronaut nurse who began with the Mercury Seven, America's first astronauts. There were also the women who transferred their sewing talents to a more unusual application.

Wang Yaping broadcasting from China's Tiangong-1 space station in 2013

ABOVE LEFT: Margaret Hamilton receives the Presidential Medal of Freedom in 2016

ABOVE: Mathematician Mary Jackson at work in NASA Langley

RIGHT: Judith Love Cohen worked as an aviation and space engineer from 1952 to 1990

BELOW: Samantha Cristoforetti holds the record for the longest single spaceflight for a woman

GETTY IMAGES, ALAMY, ESA/NASA, WIKIPEDIA COMMONS, NASA/LANGLEY

FIRST WOMAN ON THE MOON

NASA has pledged to return to the Moon by 2024. "The first woman," said current US Vice President Mike Pence, "and the next man on the Moon will both be American astronauts, launched by American rockets from American soil."

NASA's 38 active astronauts include 12 women. These range from experienced astronauts such as Sunita Williams, Kathleen Rubins and Stephanie Wilson, to Jessica Meir, Jeanette Epps and Nicole Mann, who have their first upcoming missions. Any of the 12 could be assigned for a lunar landing. Christina Koch could be a serious contender. She is currently on board the ISS and will remain there until February 2020, making it the longest single-duration stay in space by a woman.

ESA is supplying NASA with a European service module for its Orion spacecraft. Assuming this is how NASA astronauts will be delivered to the lunar surface, an ESA astronaut may also be on board. Although it sounds like the US is getting priority on those important first steps, ESA astronaut Samantha Cristoforetti must be a favourite.

America's self-imposed 2024 deadline was no doubt prompted by reports that China is working towards a crewed lunar landing by the mid-2020s. China's first two women in space, Liu Yang and Wang Yaping in 2012 and 2013, could well take their achievements one small step further. But it will be one giant leap for women's history.

THESE TRAILBLAZERS MADE IT POSSIBLE BY SHOWING THAT THEY COULD PASS THE SAME TESTS AS THE MEN

The International Latex Corporation, as ILC Dover was initially known, originally made girdles, using a variety of durable and flexible materials, and employed a number of women. In 1962 the company won a contract to make spacesuits for NASA. Its spacesuits were worn by the Apollo astronauts and today's versions are on board the ISS.

"The women seamstresses were a prime factor in making the Apollo spacesuits a success," says William Ayrey, a spacesuit test engineer and company historian for ILC Dover.

"They had to work closely with the engineers to carry out their ideas of how a properly assembled spacesuit could hold up to the challenges of working on the Moon," says Ayrey. "Often the engineers might have had an idea of how sewn parts could be put together but the seamstresses were the ones who had to make it work so they would have to show the engineers how it should be done."

According to Ayrey, working on spacesuits was "much more challenging than sewing any other typical garment or drapes."

The spacesuit was "a life-sustaining garment that could take the life of an astronaut if it failed. Some seams included what was called a blind-stitch," he says, "where the seamstress could not see what was being sewn. She had to feel underneath as it was being assembled."

The lives of the Apollo astronauts depended on the seamstresses' skills and their work was appreciated. "The women did get proper credit and were often selected to witness the Apollo launches as a reward," says Ayrey. "The astronauts liked to visit with the seamstresses when they came to ILC Dover for their fit-checks in their space suits and recognise the women's work."

Even modern NASA spacesuits are more likely than not to have been put together by women since, according to Ayrey, there is currently only one man on the team at ILC Dover. "The spacesuits are still very labour intensive and they remain a life-critical item."

THE MERCURY 13

Today at NASA there are women doing almost every conceivable job – there are female mission controllers, scientists, engineers, managers, flight surgeons and, of course, there are also women in the more attention-grabbing roles such as astronaut. Some women, like Dr Ellen Ochoa, have also managed to combine a number of roles; Ochoa's been an astronaut, an engineer and from 2013 to 2018 was the director of NASA's Johnson Space Center.

Despite Soviet cosmonaut Valentina Tereshkova upstaging the Americans in 1963 by becoming the first woman in space, and despite the number of women employed behind the scenes during the Apollo programme, not one American woman went to the Moon. This was not only a missed opportunity and but also a missed propaganda coup because the US had women ready to become astronauts years earlier.

TOP: The seven surviving members of the Mercury 13, pictured in 1995. From left: Gene Nora Jessen, Wally Funk, Jerrie Cobb, Jerri Truhill, Sarah Rutley, Myrtle Cagle and Bernice Steadman

ABOVE: Astronaut and former director of the Johnson Space Center Dr Ellen Ochoa

RIGHT: Christina Koch upgrades the ISS's power storage capacity during a spacewalk in March 2019

NASA/PL X3

Before Apollo, during Project Mercury when America chose its first seven (all male) astronauts, the same medical director who devised the selection tests recruited female pilots on a privately funded 'Woman in Space' programme. Dr Randolph Lovelace wanted to see if women had the right stuff too.

Lovelace's test case was aviator Jerrie Cobb in 1960. She performed so well that Lovelace extended the tests to other female pilots. The women who succeeded between 1960-1961 are now collectively known as the Mercury 13. The youngest was Wally Funk. The oldest was Janey Hart, aged 40 with eight children.

Hart, together with Cobb, tried but failed to get NASA to allow women astronauts at a congressional hearing in 1962. Afterwards Hart received hate mail asking her to stay at home with her children. NASA wouldn't admit women into its astronaut corps until 1978 but these trailblazers helped make it possible by showing that they could pass the same tests as the men.

Funk refers to that time as being a "good-old-boy network" and remains determined, at the age of 80, to get into space, so much so that she's purchased a Virgin Galactic ticket. Unlike Cobb, who died recently aged 88, Funk may actually make it.

Three of the Mercury Seven – Alan Shepard, Deke Slayton and Wally Schirra – all went on to become Apollo astronauts. So if the Mercury 13 had been admitted to NASA's ranks back in the early 1960s, one of those women – possibly even Funk herself – could also have been part of humanity's excursions to the Moon.

The many women involved during the Apollo missions, these ladies who launched, are inspirational. But just imagine how society would have viewed the roles of the sexes today if just one of those Moon walkers – who continue to receive worldwide admiration – had been a woman. **SF**

by **SUE NELSON** *(@ScienceNelson)*
Sue is a science journalist and author of Wally Funk's Race For Space

Badges of honour

Beginning in tragedy and ending in triumph, the Apollo missions are the pinnacle of mankind's space adventure. Every Apollo crew has a different story to tell and its own unique mission patch

words by CLIVE SOMERVILLE and GRAHAM SOUTHORN

Neil Armstrong's famous words "the Eagle has landed" immortalised the lunar module that carried the Apollo 11 crew to the Moon's surface. Strange as it may seem, the name of this craft came from the mission's official patch.

Patches originated in the US military, where air crews came up with their own designs to represent particular missions. All the early astronauts were military men, so they took the practice with them to NASA. By the time of Apollo 11, sophisticated designs were drawn up by professional artists and silk-screened onto non-flammable 'beta cloth'.

Walter A Weber's 1950 painting for *National Geographic Magazine* provided the inspiration for the eagle on the Apollo 11 patch

The Apollo 11 patch was something of a departure, however. The crew opted to leave off their own names so it could represent all of the people involved in the mission. The idea of an eagle originally came from Armstrong's backup, Jim Lovell, but it was Michael Collins who was instrumental in choosing the final design. Collins recalled the moment of inspiration in his 1974 autobiography *Carrying The Fire*: "Of course! What better symbol – eagles landed, didn't they?"

Back at home, Collins leafed through a *National Geographic* book on birds and found the ideal image: a bald eagle, its wings partially folded, swooping down with its "landing gear extended". Collins traced the picture and sketched in the Moon's surface behind it, adding a small Earth in the background. He later confessed that he drew the Earth wrong – it should have been dark at the bottom and lit by sunlight at the top.

After that, the patch's precise evolution is uncertain, although early sketches were prepared by Allen A Stevens of Rockwell International, a NASA contractor who designed most, if not all, prior Apollo patches. His designs for Apollo 11 incorporate the names of the crew and the Roman numerals XI – in one version the eagle carries them in its talons. The Roman numerals were dropped because Armstrong believed the number '11' would be more easily understood around the world.

There was still something missing, however, and it was the crew's simulator instructor, Tom Wilson, who came up with it. "Why not an olive branch as a symbol of our peaceful expedition? Beautiful! Where do eagles carry olive branches? In their beaks, naturally," wrote Collins.

After he'd sketched in the olive branch, Collins, together with Buzz Aldrin and Armstrong,

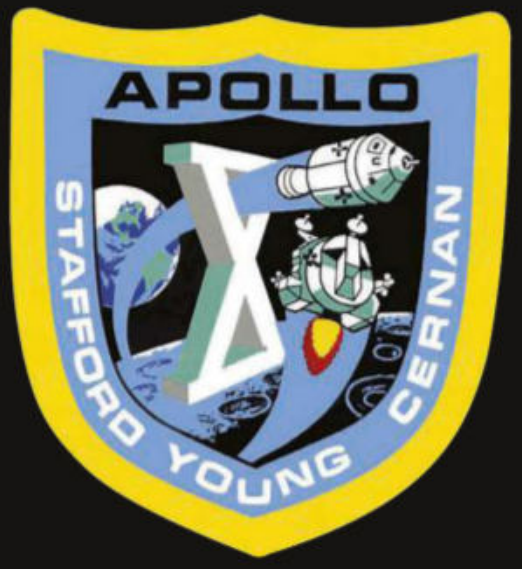
NASA/JSC


GRISSOM
WHITE
CHAFFEE
APOLLO 1


VII
SCHIRRA · EISELE · CUNNINGHAM


BORMAN LOVELL ANDERS


McDIVITT SCOTT SCHWEICKART
USA
APOLLO IX


APOLLO
STAFFORD YOUNG CERNAN


APOLLO 11


APOLLO XII
Conrad • Gordon • Bean


APOLLO XIII
EX LUNA, SCIENTIA


APOLLO 14
Shepard
Roosa
Mitchell


APOLLO 15
SCOTT WORDEN IRWIN


APOLLO 16
YOUNG • MATTINGLY • DUKE


APOLLO XVII
CERNAN • EVANS • SCHMITT

Collins found the ideal image: a bald eagle, with its “landing gear extended”

picked a naturalistic black for the sky, with blue and gold around the edge. NASA illustrator James R Cooper finished the artwork and the crew sent it to Washington to be rubber-stamped. Approval, however, wasn't forthcoming. “The eagle's powerful talons, extended stiffly below him, were unacceptable. It was too hostile, too warlike,” recalled Collins. The solution was simply to move the olive branch from the eagle's beak to its feet, although Collins wasn't happy with the finished result. He thought the bird looked a little uncomfortable.

ABOVE: **NASA artist James R Cooper works on the Apollo 11 patch design**

MOMENTOS FROM THE MOON

Today, original mission patches are extremely valuable. Beta cloths flown to the Moon can fetch $20,000 (approximately £15,300) at auction, while even embroidered patches worn by ground crew and given out as gifts sell for several hundred dollars.

And what of the original artwork? The beautiful eagle painting was by Walter A Weber, the National Geographic Society's staff artist. It was first published in the July 1950 issue of *National Geographic Magazine* and was later flipped horizontally for the publication of the book Collins found it in. The patch flipped it again, so the eagle soars from right to left – just as in Weber's original painting. **SF**

APOLLO 1

27 January 1967

COMMANDER:
Virgil 'Gus' Grissom
COMMAND PILOT:
Ed White
PILOT:
Roger Chaffee

The first manned Apollo mission, designed to orbit Earth, ended in tragedy before it began. On 27 January 1967, during a pre-launch training exercise, a fire broke out in the command module, killing the three astronauts inside – Gus Grissom, Ed White and Roger Chaffee. Grissom was one of the original Project Mercury astronauts, while White had become the first American to walk in space during the 1965 Gemini 4 mission. Apollo 1 would have been Chaffee's debut mission. All three received the Congressional Space Medal of Honor posthumously. The cause of the fire was never found, but was blamed on a lethal combination of design flaws including the command module's highly pressurised oxygen atmosphere, electrical faults, a faulty escape hatch and flammable materials.

APOLLO 7

11-22 October 1968

COMMANDER:
Walter Schirra
COMMAND MODULE PILOT:
Donn Eisele
LUNAR MODULE PILOT:
Walter Cunningham

Following the Apollo 1 disaster, Apollo 7 became the first successful manned Apollo mission, orbiting Earth for nearly 11 days (the Apollo 2 and 3 missions were redesignated as Saturn rocket tests, while Apollos 4, 5 and 6 were unmanned test flights). As well as being the first successful American three-man mission, it also marked the first use of the Saturn IB rocket to propel a manned spacecraft onto orbit. Along with the rocket, the mission allowed the crew to test the command module's new life support and control systems and, despite reported tensions between crew and mission control, the mission was declared a success. After the devastating setback of Apollo 1, it was a huge step forward. Buoyed by the outcome, NASA launched Apollo 8 just two months later.

APOLLO 8

21-27 December 1968

COMMANDER:
Frank Borman
COMMAND MODULE PILOT:
James Lovell
LUNAR MODULE PILOT:
William Anders

Apollo 8 was the first manned Apollo mission to use the Saturn V rocket and the first to orbit the Moon, just seven months before Apollo 11 would land there. Its crew became the first humans to view the far side of the Moon and witness an earthrise. "We came all this way to explore the Moon, and the most important thing is that we discovered the Earth," remarked Anders, who also took the first photos of our planet from space. Originally planned as an Earth orbit for early 1969, the mission was advanced to a full lunar mission and brought forward almost three months because of NASA's fears that the Soviet Union would advance further ahead in the space race.

BBC TWO

See footage from Apollo 8's orbit of the Moon in ***The Planets Revisited***
bbc.in/2XFqOb7

APOLLO 9

3-13 March 1969

COMMANDER:
James McDivitt
COMMAND MODULE PILOT:
David Scott
LUNAR MODULE PILOT:
Russell Schweickart

If NASA was to land astronauts on the Moon in a lunar module, it needed to test that the vehicle could detach from and re-dock with the orbiting command module. During a 10-day lunar orbit, the Apollo 9 crew performed the first manned spaceflight of a lunar module, detaching and re-docking it across a distance of more than 160km. Schweickart also performed the first spacewalk to test the backpack life-support system, while Scott tested his backpack by spacewalking in the open hatch of the command module. Crucially, the mission proved that the lunar module concept worked and that astronauts could move freely outside the modules using their backpacks. Apollo 9 was a watershed mission, moving the programme beyond lunar orbit to the real possibility of a landing.

APOLLO 10

18-26 May 1969

COMMANDER:
Thomas Stafford
COMMAND MODULE PILOT:
John Young
LUNAR MODULE PILOT:
Eugene Cernan

If Apollo 9 set the scene for a Moon landing, then Apollo 10 was the dress rehearsal. The mission launched with a clear aim: to test the full landing process, without actually landing. The Apollo 10 crew came tantalisingly close: just 14.5km from the lunar surface. For the most experienced crew of the Apollo programme, it must have seemed like touching distance and they certainly seemed confident of landing if permitted. But, aside from the important success of their 'dry run' mission, the crew had to content themselves with achieving the highest recorded speed for a manned vehicle, 39,897km/h, during their return to Earth. Eugene Cernan would later claim another landmark: the last man on the Moon, as commander of Apollo 17 in 1972. But for now, the stage was set for Apollo 11.

APOLLO 12

14-24 November 1969

COMMANDER:
Charles 'Pete' Conrad
COMMAND MODULE PILOT:
Richard Gordon
LUNAR MODULE PILOT:
Alan Bean

Four months after Apollo 11 realised the dream, Apollo 12 answered the question on everyone's lips: what now? Commander Charles 'Pete' Conrad and lunar module pilot Alan Bean landed their lunar module on the rugged Ocean of Storms about 1,500km west of the Apollo 11 site as command module pilot Richard F Gordon orbited above. The aim was to see if a module could be landed on a pre-determined spot with rougher terrain, since this was often the most geologically interesting. Conrad and Bean achieved a textbook landing in contrast to the heart-in-mouth touchdown of Apollo 11. Climbing down the ladder, the not-so-tall Conrad looked down at the lunar surface a metre below and joked, "Man, that may have been a small one for Neil, but that's a long one for me!"

APOLLO 13

11 -17 April 1970

COMMANDER:
James Lovell
COMMAND MODULE PILOT:
John 'Jack' Swigert
LUNAR MODULE PILOT:
Fred Haise

If Apollo 12 had been a relaxed mission, its successor was anything but. Apollo 13's aim was a third lunar landing but this was replaced by a more pressing mission, survival, after an oxygen tank exploded in the command service module. The crew were forced to shut down the command module to conserve the remaining power and oxygen for re-entry, and use the lunar module as a lifeboat. Along with freezing temperatures and limited water, the crew faced asphyxiation from the carbon dioxide they were exhaling into the confined space. Mission control's engineering team devised an air filtration system using the lunar module's cleaning facility and instructed the Apollo crew how to build it. By returning the astronauts safely to Earth, the mission was deemed a 'successful failure'.

APOLLO 14

31 Jan – 9 Feb 1971

COMMANDER:
Alan B Shepard Jr
COMMAND MODULE PILOT:
Stuart Roosa
LUNAR MODULE PILOT:
Edgar Mitchell

NASA's eighth manned mission landed on the Moon's hilly Fra Mauro formation, the site intended for its ill-fated predecessor. As well as a reminder of NASA's ability to land a module on uneven ground, Apollo 14 provided the first colour television images from the Moon and a chance to study the Moon's geological history through the rocks surrounding the landing site. Commander Alan Shepard and lunar module pilot Edgar Mitchell carried out several surface studies of the material and collected over 42kg of rocks for further analysis, as command module pilot Stuart Roosa orbited above. As well as a scientific success, the mission held personal significance for Shepard, who had overcome Ménière's Disease, an inner ear disorder, to be there. He celebrated by being the first man to hit a golf ball on the Moon.

APOLLO 15

26 July – 7 August 1971

COMMANDER:
David Scott
COMMAND MODULE PILOT:
Alfred Worden
LUNAR MODULE PILOT:
James Irwin

Having landed on the Moon, NASA was beginning to think that was the easy bit – the hard part was staying there. To this end, Apollo 15 launched as the first of the 'J' missions, designed for a longer stay. David Scott and James Irwin spent nearly three days on the surface, using the lunar roving vehicle (Moon buggy) for the first time to gather rock samples from further afield and conduct more detailed scientific studies. Alfred Worden was also busy in orbit using a scientific instrument module (SIM) to study the Moon from above. The SIM included, among other cutting-edge technology, a panoramic camera that provided stunning lunar images and a lunar sub-satellite to measure the Moon's gravity field and solar particles. Upon its return, NASA proudly declared Apollo 15 to be the most successful manned flight ever.

APOLLO 16

16-27 April 1972

COMMANDER:
John Young
COMMAND MODULE PILOT:
Thomas 'Ken' Mattingly
LUNAR MODULE PILOT:
Charles Duke

NASA's thoughts were now focused on extended lunar stays, but a command module malfunction meant Apollo 16's stay was cut short – and nearly didn't happen at all. "I'd practised the landing 2,000 times – and crashed 1,000 times – in a simulator," recalls Charles Duke. "But just before we were about to do it for real, we got the signal to abort. We were so close! Fortunately, mission control solved the problem and four hours later we were cleared to land." Duke and John Young landed in the Descartes Highlands. As with Apollo 15, the mission deployed the lunar rover vehicle and a low-lunar orbit subsatellite, with the crew conducting 26 experiments. In orbit, Ken Mattingly mapped the lunar equator and completed a spacewalk on the return journey to retrieve film and data from the SIM bay.

APOLLO 17

7-19 December 1972

COMMANDER:
Eugene Cernan
COMMAND MODULE PILOT:
Ronald Evans
LUNAR MODULE PILOT:
Harrison 'Jack' Schmitt

The final lunar landing was also the first night launch of an American manned spaceflight, at 12.33am EST on 7 December 1972. Apollo 17 broke other records too: the longest manned lunar landing flight, the greatest distance by a lunar vehicle (35km), the largest haul of lunar material (110.4kg) and the longest lunar orbit. Harrison Schmitt was also the only scientist on the Moon. And, of course, as the last man to climb back into the lunar module, Eugene Cernan left the last set of footprints on the lunar surface. For Ron Evans, it was to be his only space flight, having been backup for Apollo 14. The crew left a plaque, signed by them and President Nixon, which read: "Here man completed his first explorations of the Moon. December 1972 AD. May the spirit of peace in which we came be reflected in the lives of all mankind."

BBC TWO

Watch a clip of Apollo 15's astronauts collecting rock samples on the Moon in ***The Planets Revisited***
bbc.in/2IBLn4L

Relive the moment Apollo 17 astronauts discovered orange soil on the Moon in ***The Planets Revisited***
bbc.in/2UPydrj

by **CLIVE SOMERVILLE**
Clive is a Bristol-based journalist

by **GRAHAM SOUTHORN**
Graham is a former editor of BBC ***Sky At Night Magazine***

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Q&A

ALL YOUR APOLLO MISSION QUESTIONS ANSWERED

WHAT WAS THE SELECTION PROCESS FOR ASTRONAUTS AND HOW WERE THEY TRAINED?

Potential astronauts were put through their paces in rigorous physical and psychological tests. They all had to meet the basic criteria of being 25-35 years old, under 5ft 11in (1.78m), hold a degree in engineering or physical science and have logged at least 2,000 flying hours with test-pilot experience.

Their training was tough and varied. Astronauts were pushed to their limits in g-force training, learnt to manoeuvre themselves in zero gravity and even practised planting the flag. To recreate the lower gravitational pull of the Moon, astronauts were suspended sideways and had to walk along a wall. When Neil Armstrong landed, he commented that walking on the Moon was much easier than the training.

The plan for their return to Earth was for the crews to splashdown in the sea, so a lot of time was spent practising getting out of model spacecraft in swimming pools or the Gulf of Mexico. However, in case they missed the ocean on their return to Earth, all astronauts also had to learn jungle and desert survival skills.

HOW DID THE ASTRONAUTS BREATHE?

The spaceship was pressurised with an on-board oxygen source that enabled the crew to breathe normally. When they were on the Moon, astronauts wore a Portable Life Support System (PLSS), which was the large box on the back of their spacesuits. This provided them with oxygen to breathe in and removed the carbon dioxide they exhaled.

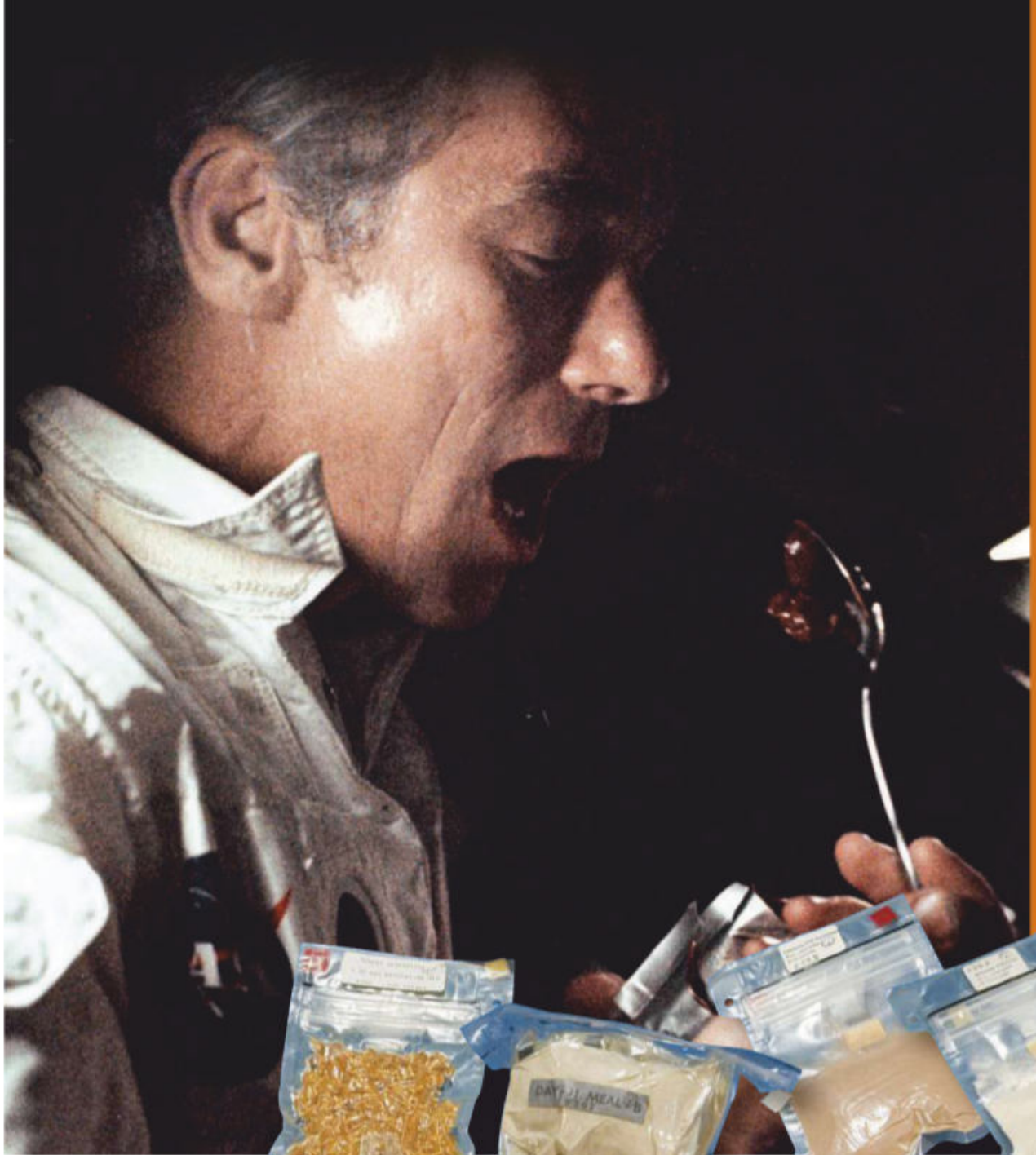
WHAT DID THE APOLLO ASTRONAUTS EAT IN SPACE?

The crew of Apollo 11 had a large selection of meals, though they were generally unimpressed with their taste and difficulty to prepare.

The larder included about 70 different freeze-dried dishes, plus a variety of drinks, each of which had to be rehydrated by adding water. This was done by inserting a probe through a valve in the plastic pouch and injecting the correct amount of fluid. Both hot and cold water were available in the command module, though it stayed at room temperature in the lunar module.

The packet was then kneaded for three minutes before the mushy contents were squeezed into the mouth or scooped up with a spoon. In-flight meals came in red, blue and white plastic bags, colour-coded for each crewmember and labelled with the date and time to eat it.

After each meal, germicide pills were put in the empty food bags to prevent fermentation and gas production. The rubbish was then stored in a waste disposal compartment.



NASA/JSC X4

WHAT'S ON THE MENU?

Meals for the Apollo missions needed to lightweight, compact and suitable for zero gravity. Crumbs had to be avoided at all costs, in case they got into equipment and caused damage but the menus gradually increased and improved as the Apollo programme progressed...

APOLLO 7

11-22 October 1968

The crew of the first American manned spaceflight got to enjoy rehydrated foods such as shrimp cocktail and chicken salad, which each had a consistency that more closely resembled baby food.

APOLLO 8

21-27 December 1968

Thermo-stabilised 'wetpack' foods were introduced on Apollo 8, which were said to be tastier and easier to prepare. On Christmas Day 1968, the Apollo 8 crew were able to tuck into turkey and gravy with spoons. This was a breakthrough: the moisture in the food meant it stayed on the spoon even in zero gravity.

APOLLO 11

16-24 July 1969

Treats of cheddar cheese and frankfurters found their way on to the menu for the first Moon landing.

APOLLO 12

14-24 November 1969

The newly introduced freeze-dehydrated scrambled eggs, proved extremely popular.

APOLLO 14

31 January-9 February 1971

A drinking device built into the lunar suits meant astronauts could keep up their fluid intake during Moonwalks.

HOW DID THE CREWS COMMUNICATE?

The astronauts communicated in the same way pilots on Earth do – via radio. Range wasn't an issue as radio signals don't stop unless they are blocked. This meant when the command module was orbiting the far side of the Moon, the command module pilot was unable to communicate with either the crew on the Moon or mission control on Earth.

HOW DID APOLLO ASTRONAUTS SLEEP?

The astronauts slept in 'sleep restraints', which were sleeping bags tied to the command module's cabin to stop them floating about. Restraints were tied under the left and right seats, and also above the right seat. They could be rolled up and stored when not in use. When on the Moon, the gravitational pull allowed astronauts to sleep on the floor of the lunar module.

DID ANYONE GET ILL IN SPACE?

Yes, Wally Schirra (right) and the rest of the Apollo 7 crew had colds. Without any gravitational pull to clear the mucus, a cold in space is very unpleasant. The crew got increasingly grumpy and refused to wear their helmets during re-entry, so that they could blow their noses. Motion sickness was also quite common. On Apollo 8, Frank Borman suffered from motion sickness and diarrhoea. His crewmates Jim Lovell and William Anders had to help him chase down particles of vomit and faeces, which were floating around the cabin.

HOW DID APOLLO CREWS GO TO THE TOILET IN SPACE?

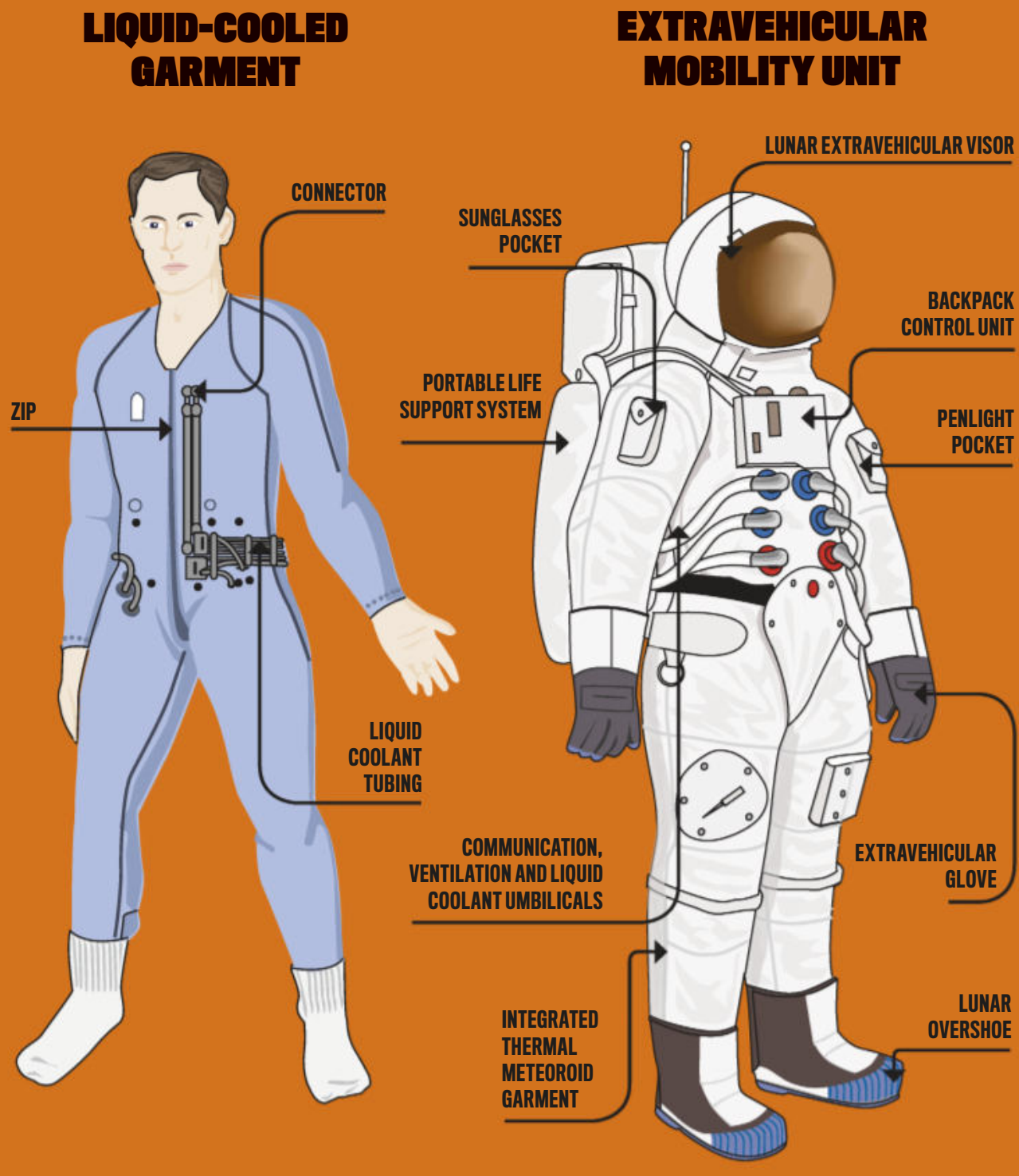
This was definitely one of the least pleasant aspects of life in space. For bowel movements, astronauts taped a plastic bag to their buttocks. The lack of gravitational pull was an issue that was never overcome on the Apollo missions. As a result, a finger-sized pocket had to be included in the side of the bag so the crewmen could separate themselves from their faeces once they were finished. They then had to pop in a capsule of germicide and knead the two together. The Apollo 7 crew returned with a memo that read: "Get naked, allow an hour, have plenty of tissues handy…" Even with this advice it went wrong on Apollo 10, when astronauts encountered "a turd floating through the air". Twice.

Urinating, in comparison, was much easier. Astronauts strapped on a rubber pouch, which came in three sizes – small, medium and large. Michael Collins remarked that the Apollo 11 crew referred to them in the more light-hearted terms: "extra large, immense and unbelievable". These were attached to a hose that, when the valve was opened, would suck the urine into space. This wasn't as simple as it may seem. Open the valve too soon and your private parts would be painfully sucked in. Open it too late and urine droplets would float all over the spacecraft… and the unimpressed members of your crew.

NASA/ISC X4 ILLUSTRATION: PAUL WOOTTON

WHAT DID THE CREW WEAR?

The crew each had three outfits. The first was a cotton all-in-one undergarment. The second was referred to as the 'inflight coverall garment' and consisted of a jacket, a pair of trousers and a pair of boots. This was made from Teflon as it was non-flammable and did not cause skin irritation. Finally, there was the space suit, also known as Extravehicular Mobility Units. This was worn for lift-off, re-entry and exploring the lunar surface. The first layer to be donned was water-cooled underwear, made up of flexible tubes embedded in a mesh fabric. On top of this was a five-layer, airtight pressure garment, articulated at the knees and elbows. Then came a 13-part outer garment, designed to protect the occupant from micrometeorites, ultraviolet light and other radiation. It could sustain surface activity for up to four hours before a recharge. A chest-mounted control unit allowed the wearer to adjust the temperature and flow of oxygen.



HOW DID THE ASTRONAUTS WASH?

On board each Apollo spacecraft was a pack of dental floss, three toothbrushes and toothpaste that was safe to swallow.

The Apollo 10 crew was the first to shave in space. A lot time was spent investigating electric razors, but there was always the issue of stubble floating into the machinery and causing problems. Someone suggested using a razor and brushless shaving cream. This worked perfectly as the cream kept the hair together, which could then be wiped off.

HOW MUCH DID THE APOLLO MISSIONS COST?

A preliminary cost of $7 billion was quoted. However, NASA administrator James Webb upped the estimate to $20 billion before handing it over to Vice President Lyndon Johnson. Many were shocked by the cost, including the President, but Webb's estimate proved far more accurate. The final cost was reported to Congress in 1973 as $25.4 billion, which equates to roughly $170 billion (£110 billion) today.

20 JULY 1969

The Sea of Tranquillity

SWOOPING INTO LAND

This composite image shows Apollo 11's lunar module, the Eagle, descending towards the lunar surface to make its historic landing. Despite a couple of last-minute hiccups, the craft would successfully touch down under the control of Neil Armstrong and Buzz Aldrin.

GETTY IMAGES

TOUCHDOWN

Moments before the lunar module is due to land on the Moon, Armstrong peers out of the craft's window to see a boulder field looming into view

GETTY IMAGES

SECONDS FROM DISASTER

After a successful launch and a smooth journey to the Moon, Apollo 11 looked to be proceeding according to plan. But just as the lunar module closed in on its intended landing site, alarms began to sound...

words by PIERS BIZONY

On the evening of 20 July 1969, an age-old dream was about to be fulfilled: mankind was on the verge of touching the Moon. With the words: "Tranquility Base here. The Eagle has landed," Apollo 11 commander Neil Armstrong at last confirmed the success that everybody had hoped for. Amid that elation, it would be impossible to guess that in just another three years' time, the dream of walking on the Moon would slip beyond our reach indefinitely.

Throughout the night of 20 July, reporters were listening to every word of radio dialogue. Yet somehow, an intriguing comment from mission control's capsule communicator ('capcom'), Charlie Duke, went almost unnoticed at the time: "Roger, Tranquility, we copy you on the ground. You got a bunch of guys about to turn blue. We're breathing again. Thanks a lot."

Why had mission control been holding its collective breath? Because Apollo 11's lunar module, the Eagle, had edged close to disaster as it plunged towards the lunar surface. During its final approach, a warning light on Eagle's display suddenly started flashing. "Program alarm," said Armstrong. "1202," Aldrin confirmed.

MISSION ABORT?

At mission control, 26-year-old Steve Bales was sitting at the guidance console ('guido'), monitoring Eagle's navigation systems. "What's a 1202?" flight director ('flight') Gene Kranz demanded to know. Bales was in the spotlight. Eagle was rushing towards the Moon and the computer was saying that something was wrong. Then another warning started flashing, this time it was a 1201. Bales needed a few seconds to think. "Stand by," he replied, trying to buy time. But Armstrong needed an immediate answer.

The Apollo 11 crew maintained radio contact with mission control on Earth thanks to three dish stations spread across the globe

“Give us the reading on the 1202 alarm,” he said. In astronaut-speak, he was asking if he and Aldrin should abort the landing.

Bales had no time left to think. Making the bravest and possibly most reckless decision of his life, he announced into his headset: “We’re go on that alarm.” This was a signal for the astronauts to continue their descent.

Kranz was surprised, but he trusted his controllers and let the decision ride. Eagle plunged onwards toward the Moon. The rules on safety were clear; Bales should have asked Kranz to call off the landing, but he didn’t believe the alarms. The computer was still feeding reliable information about speed and altitude to the astronauts’ control panels, and the descent was proceeding more or less according to plan.

Now, decades later, Bales still isn’t sure about the decision he made in that moment. “Nobody really knew what was causing the problem and I couldn’t be 100 per cent sure that the judgement I was making was okay. It was based more on instinct than hard facts,” he recalls.

Just as Bales was recovering from the 1202 scare, capcom Charlie Duke radioed a terse warning up to the Eagle’s crew: “60 seconds.” Listening to the dialogue tapes, it’s impossible to tell that anything was wrong, because of the cool nature of space-flight professionals, but in technical shorthand Duke was saying to Armstrong, “You only have a minute’s worth of fuel left.” In most of the simulations that Armstrong had performed in training, he’d made it to the surface with plenty of fuel to spare by this point. So what was happening?

Everyone at mission control was nervous. Duke called out another warning: “30 seconds.” Standing behind him, chief astronaut Deke Slayton said softly, “Shut up Charlie, and let ’em land.”

Kranz and his team then saw something even more worrying on their screens. With less than 30 metres remaining before touchdown, the lunar module was pitching forward and skimming over the lunar terrain at 55km/h. Had NASA’s two best astronauts lost control of their ship?

Eagle’s engine was about to sputter and die. The instant it did so, Armstrong would have only a few seconds to pitch it upright again, using the small thrusters on the ascent stage.

NASA/JSC X2 ILLUSTRATION: PAUL WOOTTON

MISSION TIMELINE KEY EVENTS IN APOLLO 11’S JOURNEY

16 JULY 1969

Apollo 11 launches at 13:32 GMT from Kennedy Space Center on Florida’s Atlantic Coast. More than a million people camp out along nearby Cocoa Beach to watch the lift-off.

11 MINUTES, 49 SECONDS INTO FLIGHT

Having shed its huge first and second stages, Apollo 11 is travelling at 28,000km/h when it reaches Earth orbit at an altitude of 185km using the Saturn V’s S-IVB upper stage.

2 HOURS, 44 MINUTES

After a systems check, the S-IVB engine is fired a second time, for five minutes and 13 seconds, pushing Apollo 11 out of Earth orbit on a trans-lunar injection to the Moon.

MISSION CONTROL: HOUSTON

The locations of key personnel in mission control throughout the Apollo 11 mission

1 PAO The public affairs officer was the 'voice of mission control' for viewers and listeners around the world.

2 MISSION DIRECTOR The person in overall charge of the Apollo programme.

3 DIRECTOR OF FLIGHT OPERATIONS Mission control's liaison with NASA's senior management.

4 DEPARTMENT OF DEFENSE REPRESENTATIVE Military liason officer to coordinate recovery ships and aircraft.

5 O&P The operations and procedures officer monitored the application of mission procedures at every stage.

6 INCO The integrated communications officer monitored communications systems aboard both the command and lunar modules.

7 FAO The flight activities officer kept track of the mission timeline and planned unscheduled crew activities.

8 FLIGHT The flight director was in charge of every aspect of the mission, from clearing the tower to splashdown.

9 NETWORK The network controller was in charge of the ground stations in NASA's Manned Space Flight Network.

10 SURGEON The medic that monitors the crew's health and their reactions to the space environment.

11 CAPCOM The capsule communicator was the only person in mission control with a direct line to the Apollo 11 crew.

12 EECOM The electrical, environmental and consumables manager monitored the spacecraft's fuel cells, electrical and life-support systems.

13 TELMU The telemetry, electrical and EVA mobility unit officer was in charge of systems aboard the lunar module, including the astronauts' spacesuits.

14 CONTROL The control officer oversaw guidance and control for the lunar module.

15 BOOSTER The booster systems engineer monitored the Saturn V from launch until it left Earth orbit.

16 RETRO The retrofire officer tracked retrorocket firings, including those that returned Apollo 11 to Earth.

17 FIDO The flight dynamics officer assessed flight trajectories and planned major spacecraft manoeuvres.

18 GUIDO The guidance officer tracked all the data from Apollo's on-board navigational systems.

19 MAINTENANCE AND OPERATIONS SUPERVISOR The NASA engineer in charge of monitoring and ensuring the smooth running of mission control's computers.

Giant video screens gave the mission control staff an overview of the Apollo 11 operation

4 HOURS, 17 MINUTES
Coasting towards the Moon, the command service module Columbia separates, rotates 180°, docks with the lunar module and pulls it free from its housing, jettisoning the S-IVB stage.

55 HOURS, 30 MINUTES
Armstrong and Aldrin climb inside the lunar module for a quick inspection before going back into Columbia for minor mid-course corrections. The inspection is broadcast in colour.

75 HOURS, 49 MINUTES
After a three-day coast from Earth, Columbia fires its engine for six minutes to brake the combined spacecraft into lunar orbit about 200km above the surface of the Moon.

Then the landing legs might withstand the shock of an unpowered drop on to the lunar surface. Alternatively, he could hit the 'abort' switch and blast the ascent stage back into space. If anything went wrong now, the lives of the two astronauts would depend on a split-second choice between two equally unwelcome options.

Another 10 seconds crawled by. At last, Aldrin radioed, "Contact light. Mode control to auto. Engine arm off." Those were the first words spoken by a human on another world. Sadly for Aldrin, we prefer to remember Armstrong's words a few moments later: "Houston, Tranquility Base here. The Eagle has landed."

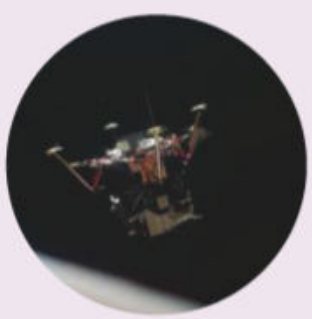
Duke's response, "You got a bunch of guys about to turn blue," was almost lost among the whoops of delight in mission control. Kranz had tears in his eyes but forced himself to stay calm. Now that Armstrong and Aldrin were on the Moon, the first thing they had to do was get ready to leave in a hurry. "Everybody settle down and check for Stay-No-Stay!" Kranz shouted to the noisy controllers around him. It wasn't yet safe to assume that the astronauts could remain on the surface.

What if the lander had been damaged on touchdown? What if one of its four legs was resting on a boulder and suddenly slipped off? Armstrong and Aldrin immediately prepared their switches for an emergency ascent. They had been on the surface for a full two minutes before Kranz finally decided that Eagle could stay where it was. When at last he lifted his hand off the desk of his console, he found it was all but glued in place by the sweat that was pouring off him.

Armstrong sounded apologetic. "Houston, that may have seemed like a very long final phase,"

MISSION TIMELINE KEY EVENTS IN APOLLO 11'S JOURNEY

95 HOURS, 20 MINUTES INTO FLIGHT
Aldrin and Armstrong transfer to the lunar module, Eagle. Five hours later they undock from Columbia and manoeuvre so that Collins can make a visual check on Eagle's condition.



101 HOURS, 36 MINUTES
Eagle's descent engine fires for 40 seconds and the craft drops towards its landing zone. It fires half an hour later to slow Eagle's descent for landing.

102 HOURS, 38 MINUTES
Eagle's alarms sound due to a computer overload, but are overridden. Six minutes later, the fuel warning light flashes as Armstrong tries to find a safe touchdown area.

ABOVE: Tensions ran high in mission control during the moments before Eagle landed on the Moon. From left capcom Charlie Duke, back-up commander Jim Lovell and back-up lunar module pilot Fred Haise

LEFT: President Richard Nixon spoke to Neil Armstrong and Buzz Aldrin while they were on the Moon

NASA/JSC X3, GETTY IMAGES

"EVERYBODY SETTLE DOWN AND CHECK FOR STAY-NO-STAY!" KRANZ SHOUTED TO THE NOISY CONTROLLERS

he explained. "[But the guidance computer's automatic targeting system] was taking us right into a crater with a large number of boulders and rocks." He had needed those precious extra seconds to manually nudge Eagle forwards a few hundred metres until he could find a safe place to land.

No apology was required. "Be advised, there are a lot of smiling faces in this room," said Duke. "There are two smiling faces up here also," replied Aldrin.

"And don't forget one in the command module," said Mike Collins, sitting alone in the orbiting Columbia.

THE WORLD IS WATCHING

Approximately 600 million people – one-fifth of the global population at the time – watched the subsequent moonwalk on television. In the US and other rich countries, many families had their own TV sets. In poorer nations, people huddled around TVs rigged up in community halls, or even in the streets.

We take it for granted today that we should be able to talk to astronauts or send instructions to space probes with relative ease. But in the 1960s, the communications network for Apollo was almost as impressive as the mission itself. Because of the Earth's constant rotation, communication with lunar astronauts required three major radio dish stations spaced at approximately 120° intervals around the planet: one in Goldstone, California; one in Australia, near Canberra; and one at Robledo de Chavela, near Madrid. 'Passive' radio astronomy dishes at other locations also listened in but could not transmit anything back to Apollo.

On the night of the moonwalk, BBC coverage of events from mission control was relayed from Houston to a radio dish in Maryland, then bounced off the Intelsat III satellite, in geosynchronous orbit above the Pacific, and down to a radio receiving dish at Goonhilly in Cornwall, from where it was fed to the BBC in London. The first radio dish on Earth to receive pictures from the Moon was the Australian station at Honeysuckle Creek near Canberra, much to the delight of its staff.

Many media commentators thought that the Apollo programme was a waste of money while so many people around the world remained poor. But when Armstrong and Aldrin finally ➤

102 HOURS, 45 MINUTES
Armstrong guides Eagle to land on Mare Tranquillitatis (the Sea of Tranquility), just over 300m from the planned landing site, using the engine's last few seconds of thrust.

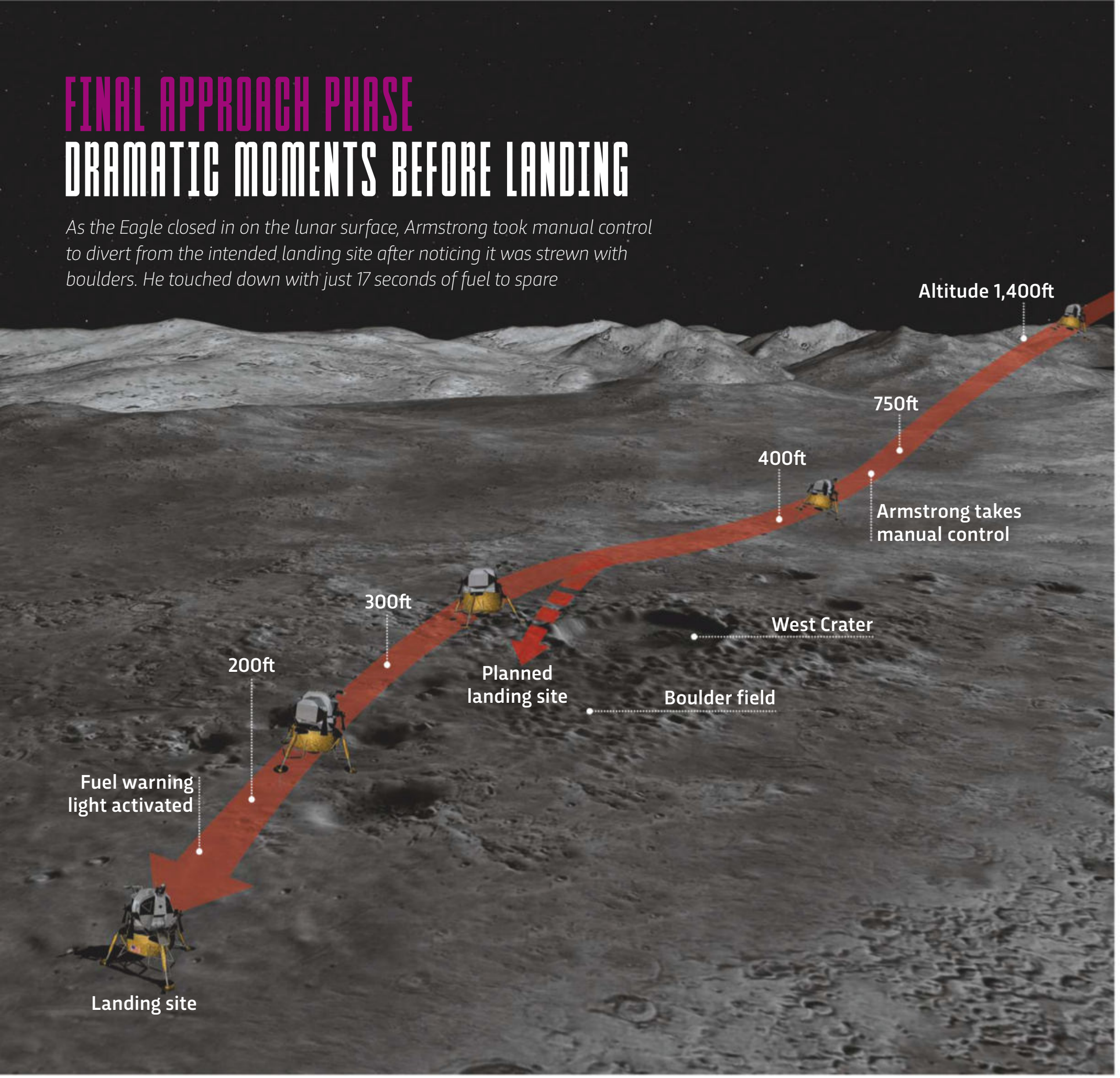
109 HOURS, 24 MINUTES
Armstrong steps off the lander module and makes the first human footprint on the Moon. After testing the surface, he says: "That's one small step for a man, one giant leap for mankind."

109 HOURS, 33 MINUTES
Armstrong collects 'contingency samples', a few pieces of Moon rock gathered from the area close to the lunar module, for immediate loading in case Eagle needs to leave urgently.

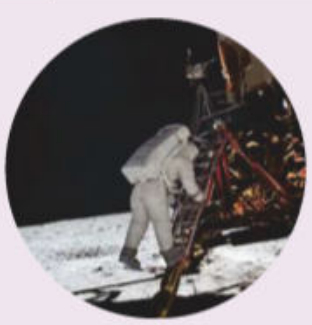
FINAL APPROACH PHASE

DRAMATIC MOMENTS BEFORE LANDING

As the Eagle closed in on the lunar surface, Armstrong took manual control to divert from the intended landing site after noticing it was strewn with boulders. He touched down with just 17 seconds of fuel to spare



MISSION TIMELINE KEY EVENTS IN APOLLO 11'S JOURNEY



109 HOURS, 39 MINUTES
Aldrin joins Armstrong on the surface, where he helps to unveil the commemorative plaque and set up a seismometer, laser reflector and solar wind collector.

124 HOURS, 22 MINUTES
After Armstrong and Aldrin's moonwalk, Eagle's ascent stage lifts off and makes a smooth climb back to lunar orbit, with no alarms or unexpected events.

128 HOURS, 3 MINUTES
After 27 hours, 51 minutes apart, Eagle and Columbia re-dock. Armstrong and Aldrin transfer their kit then rejoin Collins. Eagle's ascent stage is left in lunar orbit.

made it onto the lunar surface, even the sternest critics paused to acknowledge a unique and uplifting event in the history of our species.

During the moonwalk, President Richard Nixon spoke to the astronauts, basking in their reflected glory even though he had done nothing to make Apollo possible. In fact, behind the scenes, Nixon was shutting down the Saturn V factories and curtailing NASA's budgets. By the Christmas of 1972, the lunar missions would be over.

COURSE FOR HOME

When Eagle's ascent stage flew back up from the surface and safely re-docked with the orbiting command module Columbia, Collins learned just how close Armstrong had come to running out of fuel. "Were you really down to 20 seconds?" he asked. "That's plenty of time," Armstrong replied.

For safety's sake, NASA insisted that a homecoming command module had to survive re-entry without using the service module's engine to slow it down, just in case anything went wrong with the propulsion systems, leaving a crew stranded in space. After blasting out of lunar orbit with a final engine burn that couldn't be dispensed with, Columbia's return trajectory was essentially a three-day fall towards Earth at ever-greater speed. The command module hit the atmosphere at 40,000km/h.

NASA tried to portray the hazards of Apollo missions as routine and predictable. This cautious public relations strategy backfired, however, as some of the drama got lost amid the bland press statements. After Apollo 11, the public soon grew bored of space exploration. Nevertheless, it's impossible not to appreciate just how heroic and extraordinary that mission really was.

NASA officials and engineers in mission control celebrate the Apollo 11 Moon landing

BBC TWO

*Watch footage of Apollo's descent to the lunar surface – **Neil Armstrong: First Man On the Moon** bbc.in/2XCccsR*

As for Steve Bales, he collected a certificate from NASA and a medal from President Nixon, for 'saving' the Apollo 11 mission. He often wondered what they might have given him if he'd been wrong.

Post-flight analysis revealed that the lunar module's computer glitch (one that could have pitched America into the greatest public relations disaster in modern history) was similar to the problems encountered by Apollo 10, which Houston thought it had resolved before launching Apollo 11. The lunar module's computer was struggling to handle data from two radars simultaneously and came close to overloading. Close, but luckily, not quite over the edge. **SF**

by **PIERS BIZONY** *(@PiersBizony)*
*Piers is a science journalist and space historian. His latest book is **Moonshots: 50 Years Of NASA Space Exploration Seen Through Hasselblad Cameras***

ALAMY, NASA/JSC X2 ILLUSTRATION: PAUL WOOTTON

194 HOURS, 49 MINUTES
The command module separates from the service module as it approaches the Earth's atmosphere. Just 14 minutes later, it slams into the upper atmosphere at 40,000km/h.

195 HOURS, 18 MINUTES
Splashdown in the Pacific, 1,600km southwest of Hawaii. Before recovery by the aircraft carrier USS *Hornet*, the crew put on isolation garments to guard against possible lunar germs.

27 JULY 1969
Quarantined in a trailer, the crew are off-loaded from the USS *Hornet* in Hawaii and flown to Houston. They are released two weeks later to embark on a world tour of celebrations.

Neil Armstrong had to hurriedly find an alternative landing spot during Apollo 11's final descent on to the Moon

LAST-MINUTE ADJUSTMENTS

You're seconds away from touching down on the Moon. You've just realised the landing site is strewn with boulders. And now your fuel's running out… What do you do?

Interview by PROF JAMES R HANSEN

NASA/JSC

NEIL, COULD YOU DESCRIBE WHAT YOU WERE SEEING AS YOU WERE MAKING YOUR FINAL DESCENT DOWN TO THE LUNAR LANDING?

Our automatic pilot was taking us into an area that clearly, even from high altitude, looked like a marginal area, with a very large crater surrounded by fields of large boulders. As we got closer I could see that this was not the place where I wanted to be landing. I'd probably be able to avoid the big boulders, but never having landed this craft before I didn't know how well I'd be able to manoeuvre to a particular landing point; if I tried to get down into a pretty tight spot, that probably wouldn't be fun. So I'd better find a larger, more open area without imminent dangers on all sides.

Also, the slope on the side of the big crater was substantial and I didn't think we should be trying to land on a steep slope. I don't know what the slope was exactly but it was far from level. So I just took over manually and flew it on out to the west at a decent rate of speed and tried to find someplace that looked substantially better.

HAD YOU EVER FLOWN THE LUNAR MODULE IN THAT FASHION BEFORE, EVEN IN SIMULATION?

In the lunar lander training vehicle we did some of that. It was a matter of using those types of techniques and traversing over the ground. If I had had a little more experience in the machine, I might have been a little more aggressive with how fast I tried to get over the difficult terrain, but it didn't seem prudent to be making any very large moves in terms of the spacecraft's attitude.

I just didn't have enough flying experience in the machine in those conditions to know how well it was going to react and how comfortable it would be. Fortunately it flew better than I expected. I certainly could have gotten away with being a little more aggressive in moving more smartly away from the bad area into the better area. That might have saved us a little fuel.

FOR A LOT OF PILOTS, ISN'T THERE A PSYCHOLOGICAL TENDENCY TO WANT TO LAND 'LONG'? BUT I'M THINKING THAT WOULDN'T APPLY IN YOUR SITUATION BECAUSE LANDING

LONG IS USUALLY ON A RUNWAY, WHERE THE CONDITION AHEAD OF YOU IS KNOWN FOR A SUBSTANTIAL DISTANCE. THAT WASN'T THE CASE ON THE SEA OF TRANQUILITY...

We had to pick a spot and didn't know how much visibility we'd lose as we got down closer to the surface, so we wanted to pick a spot that was pretty good while we still had 150ft [45m] of altitude. In fact, we did start losing visibility when we got down to a little below 100ft [30m], when we started picking up dust. The dust formed a fast moving sheet, a blanket that moved away from us radially in all directions, which obscured the surface almost completely, with just some boulders sticking up through it. But those rocks actually helped a lot, because I could use them as location markers to tell our actual velocity over the ground.

Then, after finding a good area to land, it was just a matter of lowering it down relatively slowly and keeping from inducing any substantial forward or sideward motions.

WHAT ABOUT THE FUEL SUPPLY AT THIS POINT? WERE YOU ON THE VERGE OF RUNNING OUT?

Once I got below 50ft [15m], even if I ran out of fuel, I thought I'd be all right there. Our landing legs with their collapsible foam inside would probably stand a drop from 50ft. I didn't want to drop from 50ft, but once I got below 50ft I felt pretty confident that we would be all right.

YOU KEPT POWER ON RIGHT TO TOUCHDOWN?

If it wasn't all the way to touchdown it was just before. It was very close. It was a very soft touchdown. When Buzz called out, 'Contact light,' we were in this moving sheet of sand and I wasn't completely confident at that point in time that it had really touched. It might have been an anomaly or something, so I wanted to feel my way down a little closer. We may have actually touched down before I shut the engine down. The only danger with that was, if I got the engine bell too close to the surface when it was running, it was possible that we could get engine damage. Certainly, if we had landed right on top of a rock with the engine bell sticking out, that wouldn't have been good.

I KNEW WE WERE GETTING SHORT OF FUEL AND THAT WE HAD TO GET IT ON THE GROUND

HOW CRITICAL WAS YOUR FUEL SITUATION? WERE YOU VERY CLOSE TO RUNNING OUT?

I don't know if there's any way to know for sure, really. The fuel tank bottom was spherical, and it's always very difficult to have any kind of a quantity measuring system in the bottom of a spherical surface. It's very difficult to know how much is in there, particularly if the fluid in there is wandering around. Our indicator light was to go on with 30 seconds of fuel remaining, but if there was sloshing, you wouldn't know whether that light went on early or late. The important thing was that we were close enough to the surface that it didn't really matter. We

NASA/JSC

Armstrong's coolness under pressure helped him secure his spot in the Apollo programme

wouldn't lose our attitude control when we ran out of descent fuel. The engine would just quit and we would settle to the ground pretty gently.

BUT IF THE WARNING ABOUT THE FUEL RUNNING OUT HAD COME EVEN A LITTLE BIT EARLIER – OR IF MISSION CONTROL HAD GIVEN YOU A 'BINGO' FUEL CALL [THE SLANG TERM FOR THE MINIMUM FUEL REQUIRED TO MAKE A SAFE RETURN] BASED ON THEIR DATA – YOU MIGHT HAVE HAD TO ABORT?

Houston did make the call, based on their computations, and we had our light go on for 30 seconds remaining. But I'm pretty low by this time. It was not a time you would want to abort. If you're down low enough, then the safest thing to do is to continue. If we'd been at 100ft, then you would have to abort because of insufficient fuel. In the LLTV it wasn't unusual to land with 15 seconds left of fuel – we did it all the time.

SO YOU WOULD SAY THE FUEL SITUATION LOOKED MANAGEABLE TO YOU?

Yes, it did. It would have been nice if I'd had another minute of fuel to fiddle around a little bit longer, but I knew we were getting short and I knew we had to get it on the ground, and I knew we had to get it below 50ft. I wasn't panic-stricken about the fuel situation.

DESCRIBE THE ANGLE AT WHICH THE LUNAR MODULE WAS COMING DOWN THE LAST 100FT.

I liked to have some forward motion all the time during the descent. A helicopter pilot will do the same thing. It gives you a view of the landing area in front of you all the time and as soon as you stop horizontal motion and go vertical, you can't see what's directly underneath you. So until I got it very close to the surface, I wanted to keep a little forward velocity.

DESCRIBE YOUR EMOTIONS AND HOW YOU AND BUZZ ALDRIN REACTED TO ONE ANOTHER ONCE YOU REALISED THAT YOU HAD SUCCESSFULLY MADE THE LANDING.

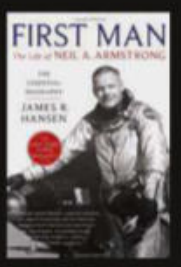
There were a few system details that we had to take care of immediately upon landing: turn certain switches off and so on. Once we got through those procedures there was time to shake hands. We had made it. So far so good. But there wasn't a lot of time for enjoying the moment because there were other things to do.

DID YOU COME UP WITH THE NAME FOR YOUR LANDING SITE, TRANQUILITY BASE? OR WAS IT CHOSEN BY THE WHOLE APOLLO 11 CREW?

No, I'm guilty of that. I told Charlie Duke about it in advance of launch so he wouldn't be surprised by the name when I used it.

DO YOU CONSIDER YOURSELF AN EXPLORER? DID YOU THINK OF YOURSELF IN THAT WAY AT THE TIME?

What I attended to was the progressive development of flight machinery. My exploration came as a byproduct of that. I flew to the Moon not so much to go there, but as part of developing the system that would allow it to happen. **SF**



*This article is taken from interviews that biographer James R Hansen conducted exclusively with Neil Armstrong while researching **First Man: The Life Of Neil Armstrong**. Hansen is a professor of history at Auburn University, Alabama.*

LANDING ON THE SEA

When the Eagle landed, it touched down in the Sea of Tranquillity. The site had been chosen for the relative safety its "magnificent desolation" offered. But as it turned out, the sea's waters weren't as smooth as expected

words by WILL GATER

While the precise landing site of the Eagle, Apollo 11's lunar module, was in the hands of Neil Armstrong in the final tense minutes of the descent, the decision to land in the Mare Tranquillitatis (the Sea of Tranquillity) had been years in the making.

It was the job of NASA's Apollo Site Selection Board to find a site. Their choice would be based on images returned by the Surveyor landers and the Lunar Orbiter spacecraft, which had photographed 99 per cent of the lunar surface by 1967. Promising sites were selected based on how smooth and obstacle-free they were, and how much fuel was required to land. The site would also have to be lit correctly at the time of landing, so that craters and other features used for navigation would be visible in sufficient relief. Safety concerns took precedence over scientific benefits.

By December 1967 the list of sites had been whittled down and, as the launch date moved closer, the smooth plains of the Sea of Tranquillity were chosen. By the time Eagle reached lunar orbit in 1969 it was heading towards an intended 'landing strip' some 19km long and 5km wide. It was only when Armstrong spotted boulders that were too small for the Lunar Orbiter images to show that he took manual control and touched down 6km beyond the originally planned destination, near West Crater. Tranquillity Base had been reached. SF

The view from the Apollo 11 lunar module's porthole shortly after Neil Armstrong and Buzz Aldring successfully touched down on the Moon

NASA/JSC X3

BBC TWO

See Charlie Duke recall his role in the Apollo 11 Moon landing
bbc.in/2UBMZwM

LANDING SITES

APOLLO 15
30 July-2 August 1971

APOLLO 17
11-14 December 1972

APOLLO 11
20-21 July 1969

APOLLO 16
21-24 April 1972

APOLLO 14
5-6 February 1971

APOLLO 12
19-20 November 1969

ABOVE: During the Moon landing, Michael Collins remained alone in the command service module (CSM), photographed here above the Sea of Tranquillity from the lunar module, just before it began its descent

APOLLO 11

Mission duration 16 – 24 July 1969

On 20 July 1969, commander Neil Armstrong and lunar module pilot Buzz Aldrin touched down triumphantly in the Moon's Sea of Tranquillity while command module pilot Michael Collins orbited above. Popular belief records the first words spoken on the Moon as, "The Eagle has landed." In fact, it was Aldrin's rather more prosaic, "Contact light." as a probe on one of the module's legs touched the surface. They had landed it with only moments to spare – it's estimated they had around 25 seconds of fuel remaining – and narrowly avoided a boulder-strewn crater. Shortly after that, at 10.56pm EDT, Armstrong set his left foot on the surface of the Moon and made history in front of 600 million viewers. He and Aldrin spent the next 21 hours and 36 minutes there before returning to Earth with Collins and 22kg of lunar material on 22 July.

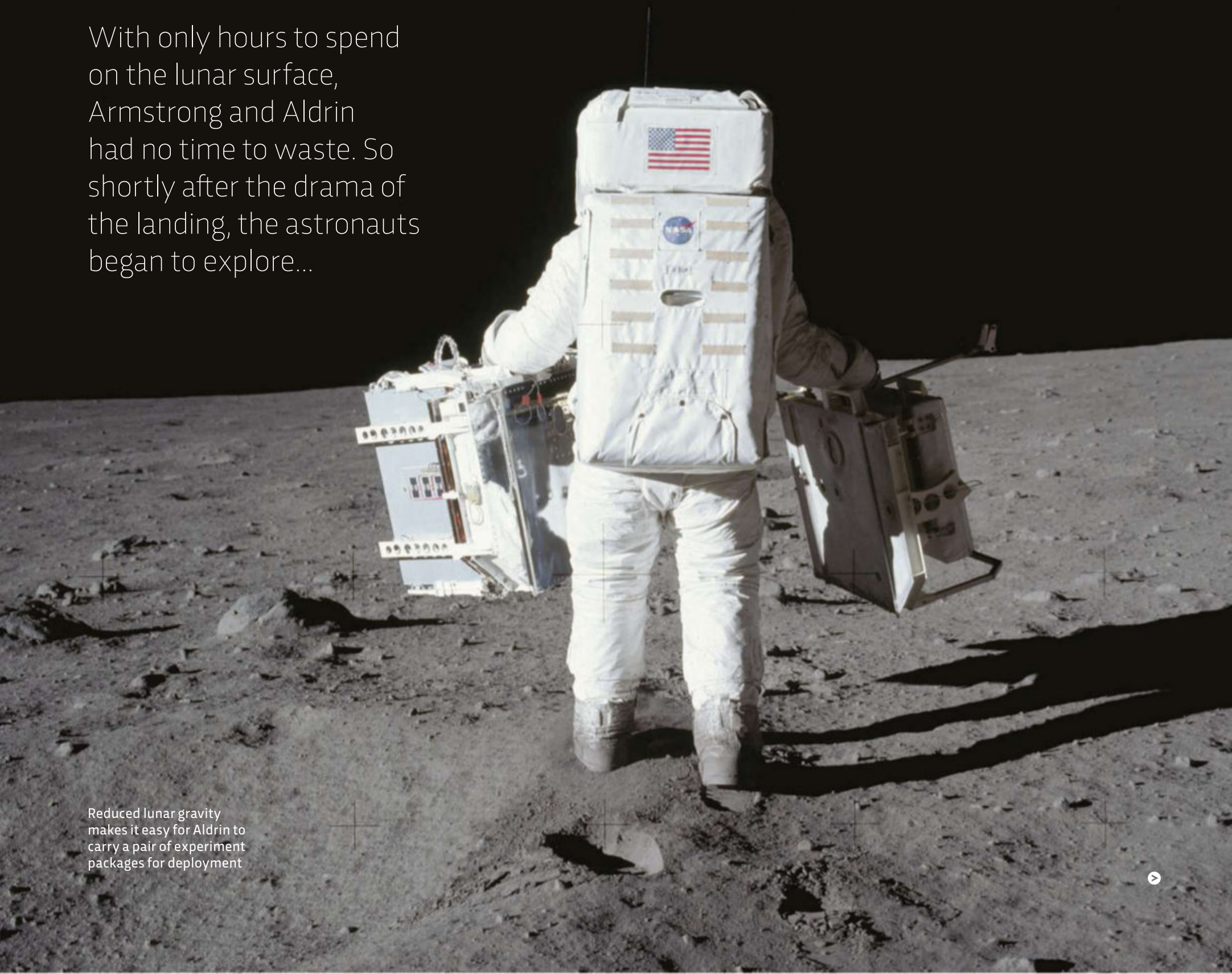
by WILL GATER *(@willgater)*
Will is an astronomy journalist, author and presenter

Around 90 minutes into his moonwalk, Buzz Aldrin took this photo of the American flag planted in the lunar landscape

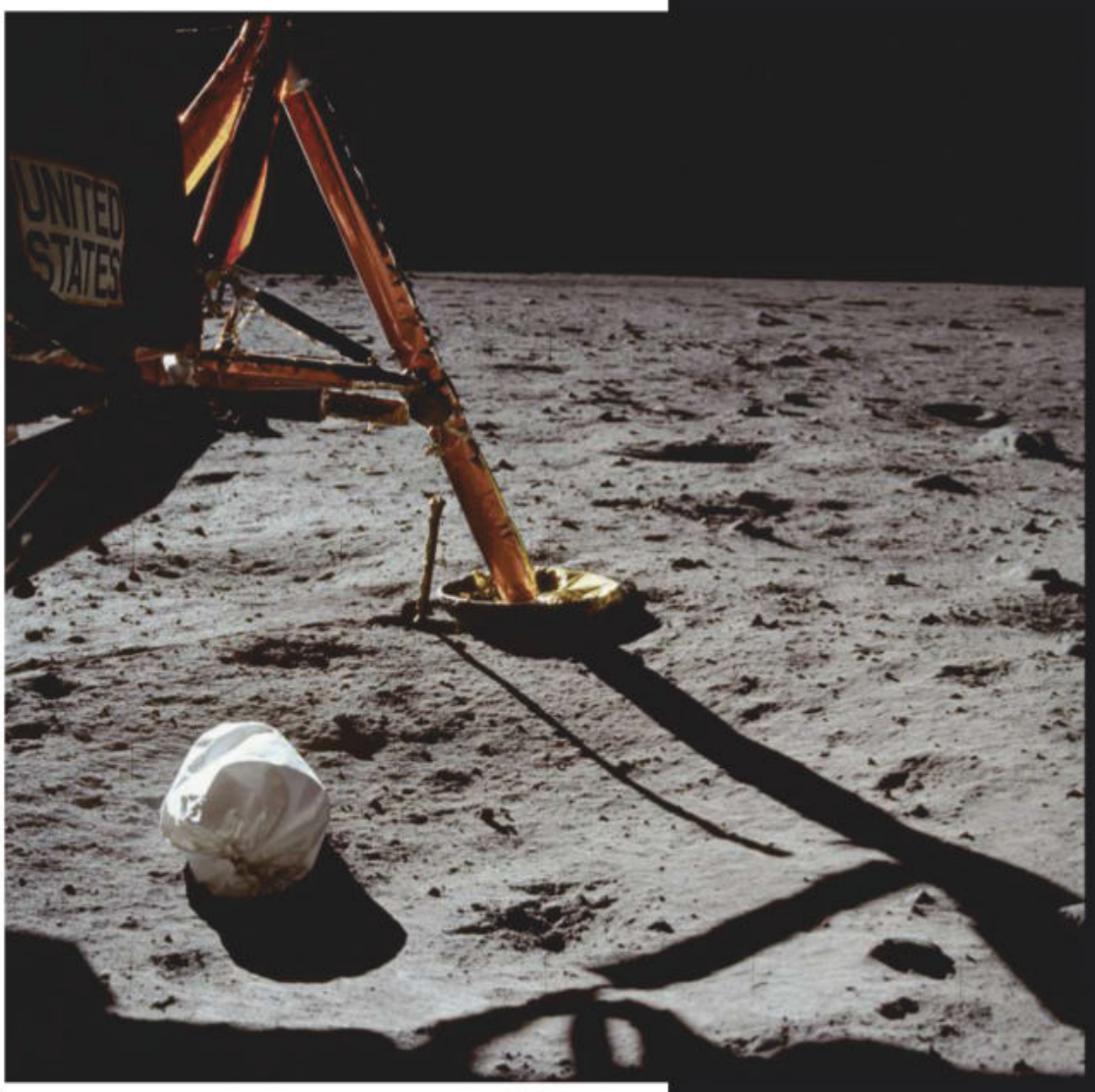
NASA/JSC X2

On the MOON

With only hours to spend on the lunar surface, Armstrong and Aldrin had no time to waste. So shortly after the drama of the landing, the astronauts began to explore...



Reduced lunar gravity makes it easy for Aldrin to carry a pair of experiment packages for deployment



ABOVE: Armstrong's first photograph on the lunar surface, taken 23 minutes into the moonwalk, shows Eagle's footpad and strut support, plus a white jettison bag full of rubbish from the lunar module. The bag was left on the surface to free up space in the cramped cabin

ABOVE RIGHT: Neil Armstrong packs the samples of Moon rock he's just collected into a specially sealed rock box in preparation for their return to Earth. Taken after just one hour and 24 minutes into their explorations of the lunar surface, this photo is one of the few that show Armstrong on the Moon

RIGHT: Half an hour after stepping out of the lunar module, Armstrong captures shots of his crew-mate Aldrin making the same feet-first exit onto the Moon. It takes Aldrin three minutes to make it to the bottom of the lunar module's ladder

FAR RIGHT: Aldrin photographed the impression his spacesuit's boot left in the lunar surface so that experts back home could study its soil mechanics

NASA/JSC X5

SOLAR WIND EXPERIMENT

This experiment measured the abundances and isotopes of solar wind particles, particularly the noble gases helium, neon and argon.

It was made of very thin aluminium foil. Solar wind particles travelling at hundreds of kilometres a second penetrated the foil and got trapped. The experiment was set up about six metres from the lunar module and packed up after 77 minutes on the surface.

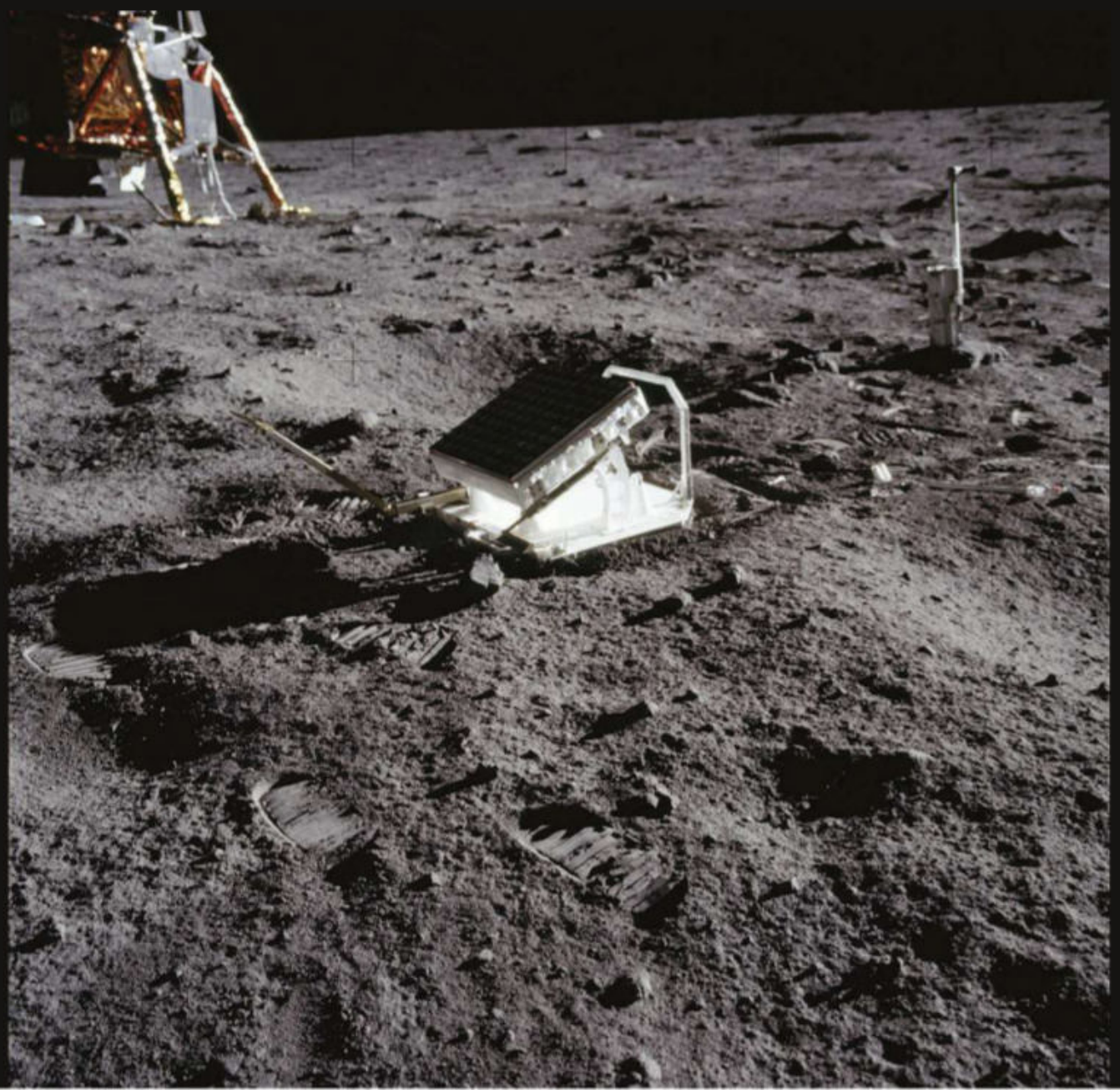
The foil was analysed in a mass spectrometer back on Earth and revealed a more detailed picture of the solar wind's particles than earlier remote experiments had.

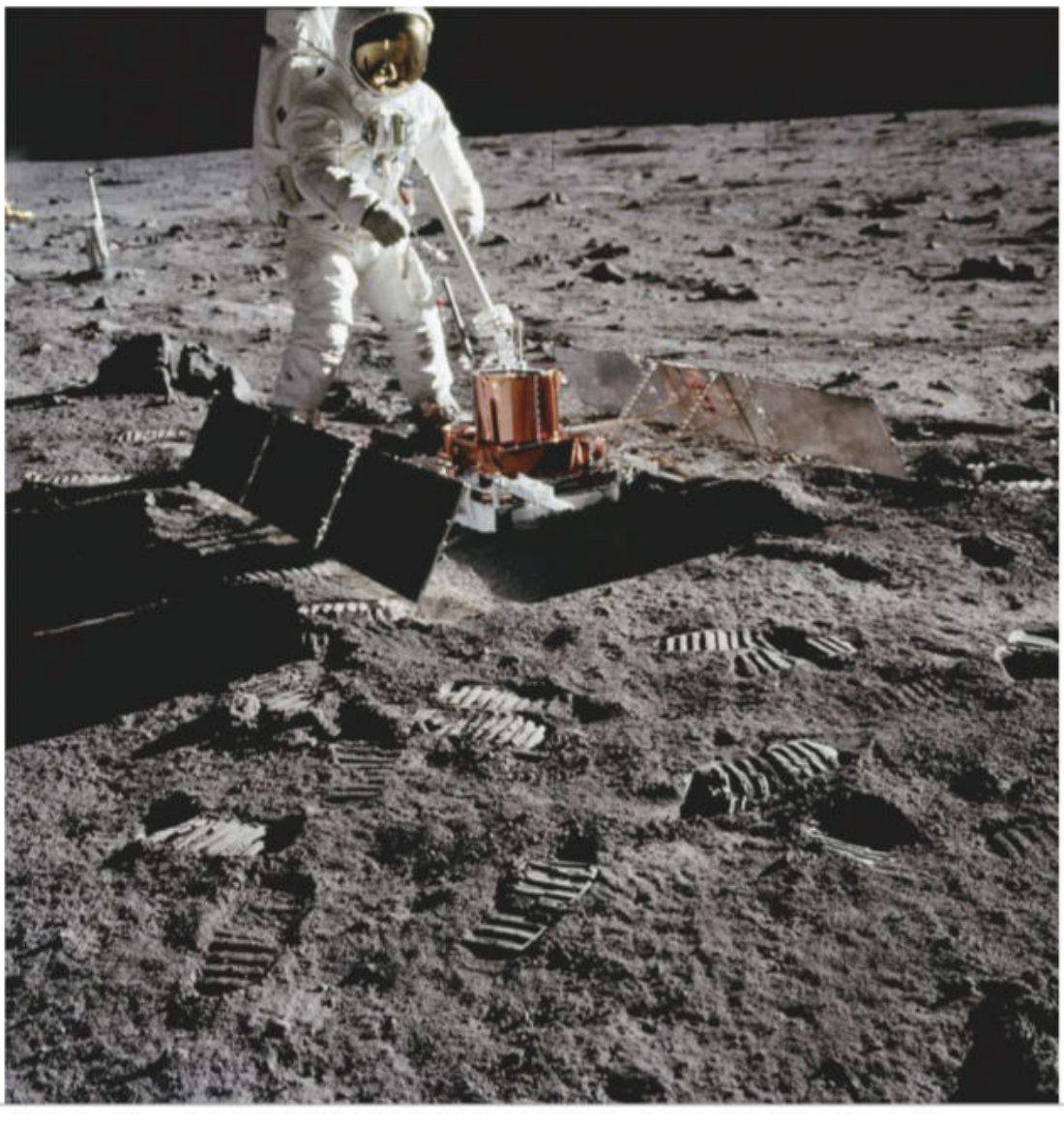
Around 60m east of the lunar module, Armstrong decided he had gone far enough and stopped to take this panoramic shot. It shows the lunar module on the left and East Crater on the right. The crater is approximately 30m wide and 4m deep

LASER RANGING RETROREFLECTOR EXPERIMENT

This first laser ranging reflector to be placed on the Moon was designed to monitor the distances between stations on Earth and the Apollo 11 landing site. The data has been used in studies of gravity, relativity and lunar geology.

Made up of 100 small, fused silica cubes that reflect laser light directly back to its source, the reflector was placed about 14m from the lunar module. The first measurements were made at Lick Observatory on 1 August 1969 and are still being taken today.





NASA/JSC X3

PASSIVE SEISMIC EXPERIMENT

Four very sensitive seismometers measured moonquakes in the lunar crust or vibrations caused by meteorite impacts. Any relative motion was recorded as an electrical impulse and sent directly to Earth. Power came from two solar panels and a thermal shroud protected it from the extremes changes of temperature.

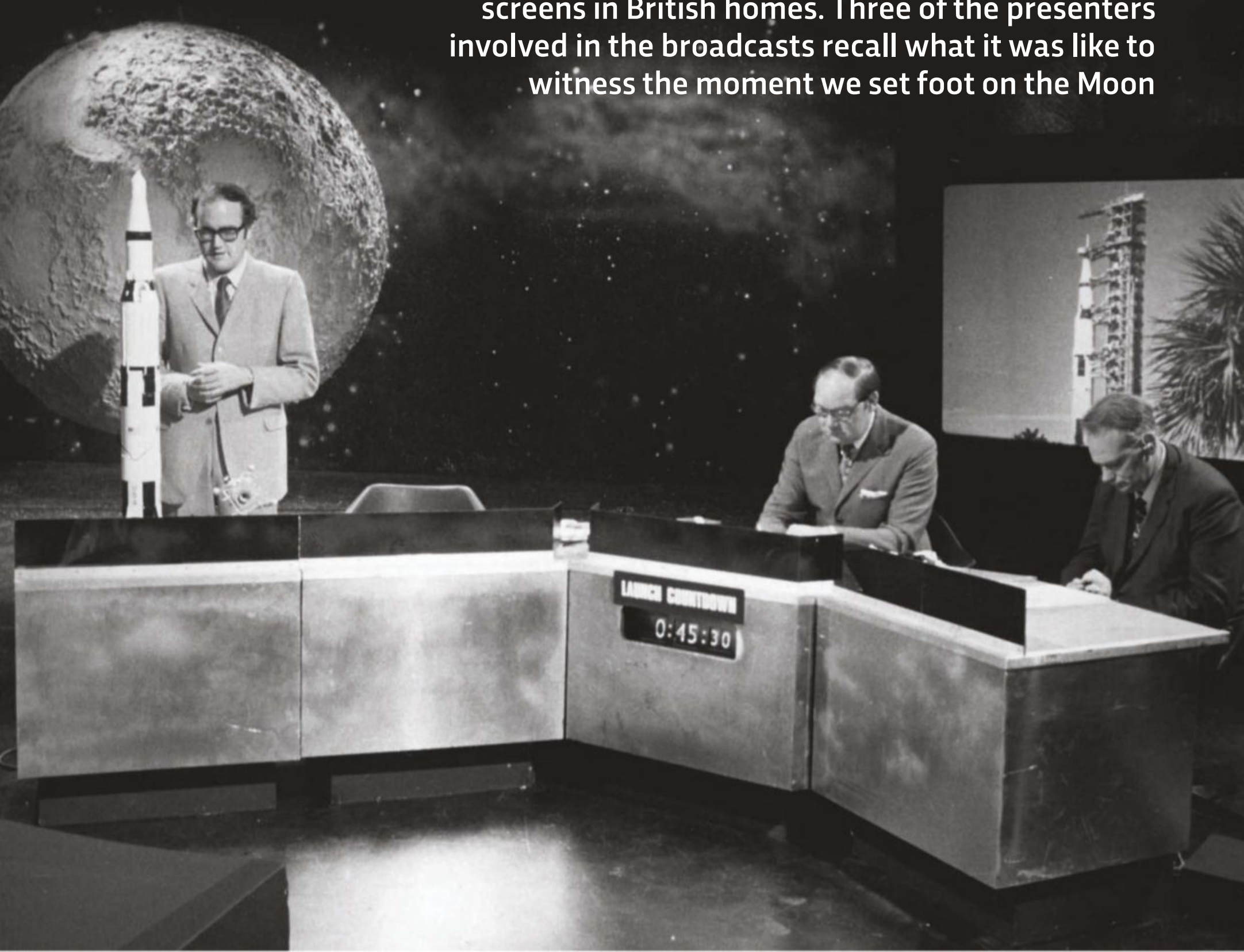
The 21-day experiment found that seismic events on the Moon are less frequent than earthquakes on Earth. It also recorded erosion events, thought to be landslides along the walls of relatively young craters.

BBC iPlayer

Watch a clip about the Apollo 11 Moon experiments
bbc.in/2Vdjo1l

ON AIR, ON THE MOON

The BBC covered the historic Apollo 11 mission by reporting from Cape Kennedy and, a few days later, relaying pictures from the lunar surface to the TV screens in British homes. Three of the presenters involved in the broadcasts recall what it was like to witness the moment we set foot on the Moon



SIR PATRICK MOORE

Three years before his death in 2012, the astronomer and presenter of the BBC's *The Sky At Night* looked back on his experience of the Apollo 11 Moon landing

Since I had been mixed up in the observation of the Moon for many, many years, I was the astronomer on the scene for the BBC's coverage of the Apollo 11 mission. When it came to anything to do with astronomy or the Moon it would be my cue to commentate. I remained in the studio throughout the mission with James Burke [see p76], who commentated on the mechanical side of the mission, and Cliff Michelmore, who did the general commentary. And there was also the usual team buzzing around: cameramen, sound men, assistant producers and secretaries.

On the night of the Moon landing, I was nervous. At the time, there was a lot of debate about the lunar surface and whether it was covered in soft dust or whether it was solid. I'd always been sure that the lunar surface was firm and we knew something of the nature of the surface from the Russian and American landers, but there was still some doubt there. The point is that the astronauts couldn't have been rescued; if they had made a faulty landing there would have been no return.

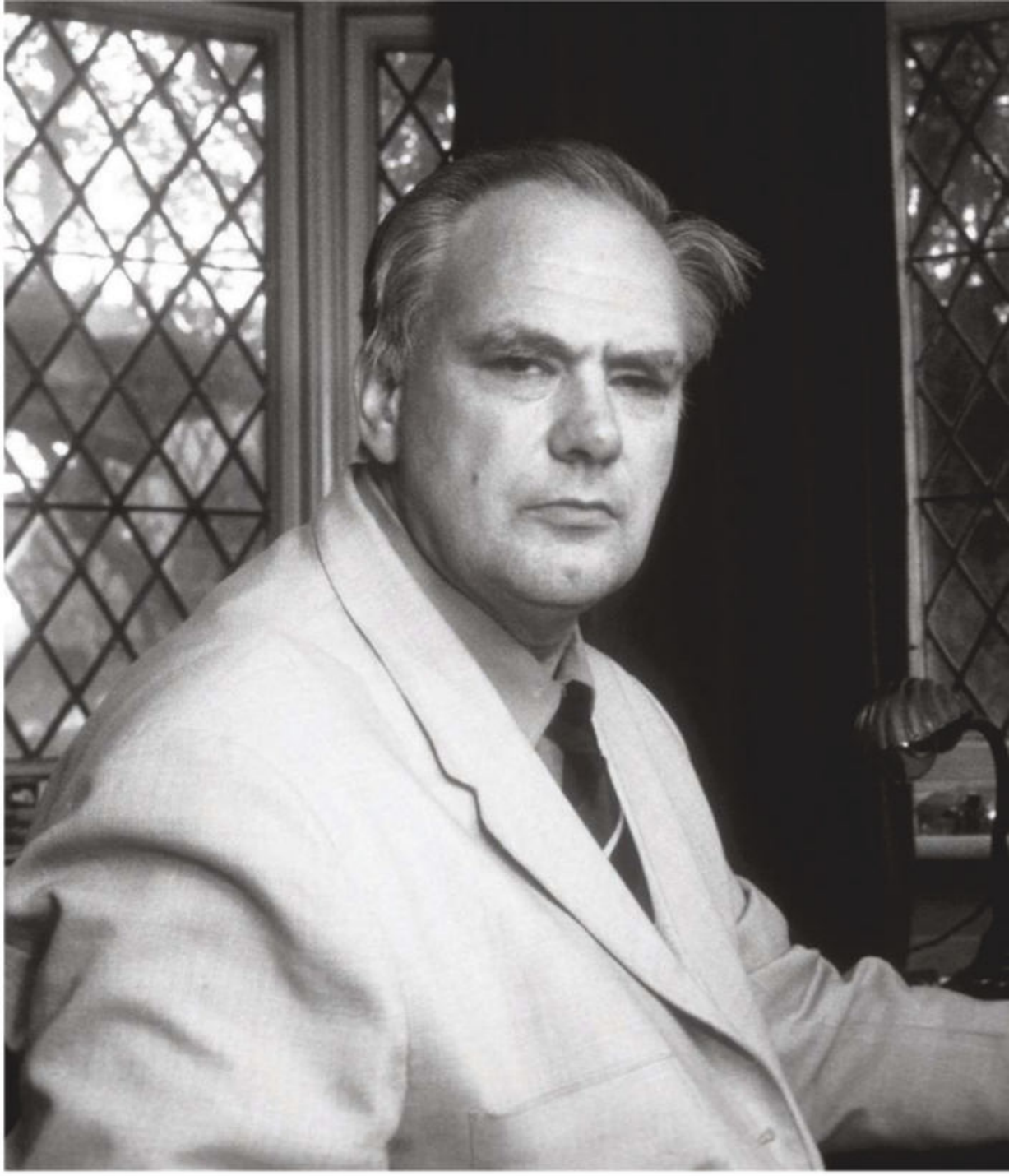
When I heard Armstrong say, "The Eagle has landed", I felt immense relief. My main thought was that they were down safely and that the worst was probably over. But it didn't end there. The other thing that made me very tense was when they blasted off the lunar surface. There was only one ascent engine on the lunar module and it had to work properly first time; luckily it did. Because I was busy commentating I didn't have time to celebrate then, but I had a large drink after the programme had finished.

My impression of the TV pictures that came from the Moon was that they looked very grainy and rough, but they were amazing for the time. They gave a very good impression of what it was like to be there: it was just as Buzz Aldrin described in his famous phrase – 'magnificent desolation' – which really hasn't been bettered. That's really what it was.

When it came to the moonwalks, I believed in saying as little as possible. I wanted people to watch this historic event without interruption and I didn't want to talk over the astronauts. If they started talking while I was talking, I stopped, even if I was in mid-sentence. I was very careful about that.

Apollo 11 didn't do a lot of science, but it confirmed what the Moon was like and it proved that we could travel to other worlds. I remember looking at the Moon through my telescope during the mission and thinking that it was amazing that there were people up there on the Sea of Tranquility.

I was immensely enthusiastic about the Apollo programme, but I think NASA was right to call it off after Apollo 17. I don't believe the cancelled missions would have added much more to our understanding and there was bound to have been an accident sooner or later. But I'm very glad to have been involved in the coverage, even in a very minor capacity.

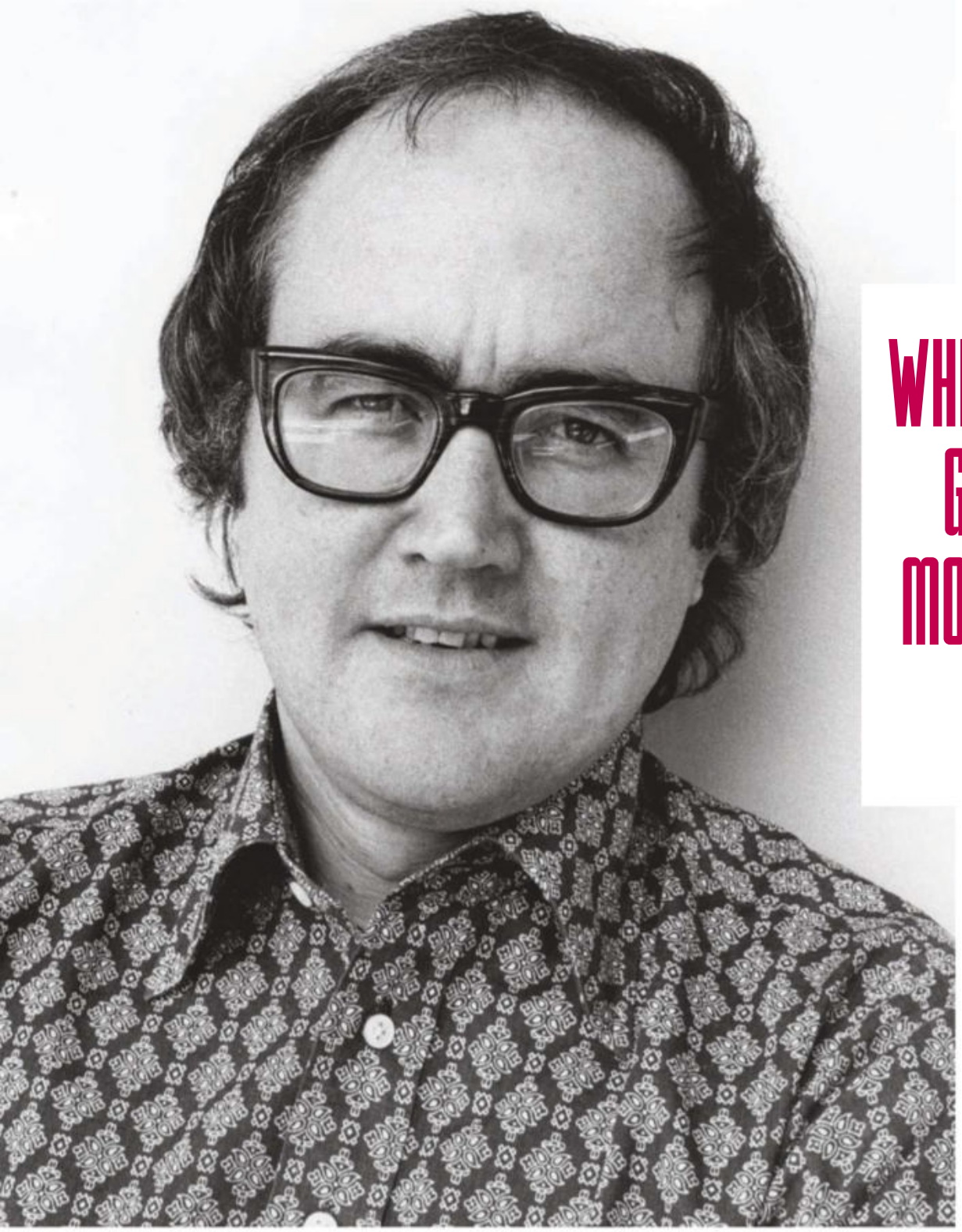


The astronomer Sir Patrick Moore was the presenter of *The Sky At Night* since its first broadcast in 1957

BBC FOUR

Watch archive footage from the ***Apollo 11 mission*** *on* ***The Sky At Night****'s 'Moon Shot' episode, due to be broadcast on 14 July*

BBC X2



Tomorrow's World presenter James Burke continues to front programmes and podcasts on emerging technology to this day

JAMES BURKE

The *Tomorrow's World* presenter doubled as the BBC's chief reporter for the Apollo missions. He recalls a long and frantic night spent commentating on an event unlike any other

The Apollo 11 coverage was unlike any other live broadcast because there was no precedent of any kind. None of us had ever done anything like it before; it wasn't like a horse race or a coronation. As I recall, we stayed on air continuously for 11 hours, from 11.30pm until 10.30am the next morning. It was the first all-night broadcast.

I remember an extremely high level of adrenaline that night, because it was a historic occasion and none of us wanted to screw up.

WHEN ARMSTRONG SAID HE WAS GOING TO STEP OFF THE LUNAR MODULE, I HELD MY BREATH AND STAYED ABSOLUTELY SILENT

When Armstrong said he was going to step off the lunar module, I held my breath and stayed absolutely silent, because what happened next was something for history. That's the trouble with live situations that you have no control over and no previous experience of: when do you speak? The worst thing would have been to have some stupid commentator talking over the top of a historical moment.

Apollo 11 was the greatest show anybody had ever seen, that much was clear. People in cities around the world were watching it on television sets. And I noticed that barometer of all public reactions, the London taxi driver, rapidly change his vocabulary. In the beginning, they'd say things like: "Big rocket, very impressive thing." And then, not long afterwards, they'd be talking about mid-course corrections. There was such fantastic public interest.

The Apollo missions were the first time that many people ever realised that we were on a planet. Those images of Earth seen from the Moon gave us, I think, the first real understanding of the vulnerability and fragility of our 'blue marble in space'. The environmental movement is one of the things that has come out of the Moon landings most strongly.

But the incomprehensible, unbelievable nature of the event has disappeared. For today's kids, it's simply a given that we once stood on another world. We have lost that sense of astonishment at the achievement in a short space of time.

NASA/JSC, BBC

MICHAEL CHARLTON

Panorama presenter Charlton, was 'on the scene' for the Apollo 11 mission, able to witness the tense atmosphere in Houston's mission control and experience the ferocity of the launch of the Saturn V rocket from Florida

I was at Cape Kennedy and Houston during the Apollo 11 mission coverage. It was my job to convey what it was like to be there, the context in which the mission was happening and the atmosphere of mission control.

At the launch, I was in the grandstand. I used to commentate on test cricket and it was rather like that. But I was quite unprepared for the noise the Saturn V made – it shook your insides. The microphone couldn't handle noise like that and we had to turn the volume down. It was an absolutely colossal sound.

They were very brave, those boys, sitting on top of what amounted to a huge bomb. I remember asking one of the earlier astronauts whether he felt at all poetic about the Moon (I had Keats's phrase, "Alone and palely loitering," in mind) and he said he didn't. So I asked, "Well, what is the Moon to you?" And he said, "A big fat target." They were test pilots first and foremost, certainly not round-shouldered academics.

They were the sort of people you could expect to keep their heads in a crisis. Take the way Aldrin talked that spacecraft down to the Moon, it was like he was helping someone back into a parking space. I thought it was extraordinary.

The Moon landing came at a useful time; it was an uplifting moment in a period of gathering cynicism and disturbance, what with the Cold War, the Vietnam War, the civil rights movement and student riots. But the Moon landing offered the restoration of hope and that was important given the threat that hung over the world back then.

It was very important too that it was a civil rather than a military programme. It was an attempt to say that rockets could be put to other uses. Nevertheless, having reported on the arms race, I was aware of what the Saturn V's precision represented in military terms: that America really could annihilate a good deal of the world. It was a most extraordinary event and I still find it rather difficult to comprehend that it actually happened. **SF**

*Watch **Panorama**'s coverage of the Apollo 11 moon landing bbc.in/2URZMjF*

I WAS QUITE UNPREPARED FOR THE NOISE THE SATURN V MADE – IT SHOOK YOUR INSIDES... IT WAS A COLOSSAL SOUND

Before the Moon landing, Michael Charlton reported on JFK's assassination for *Panorama*

24 JULY 1969

North Pacific

A DROP IN THE OCEAN

After passing through Earth's atmosphere and parachuting into the Pacific, the returning Apollo 11 crew is met by a recovery team from the USS *Hornet*. The crew and their craft will be airlifted to Houston for close inspection.

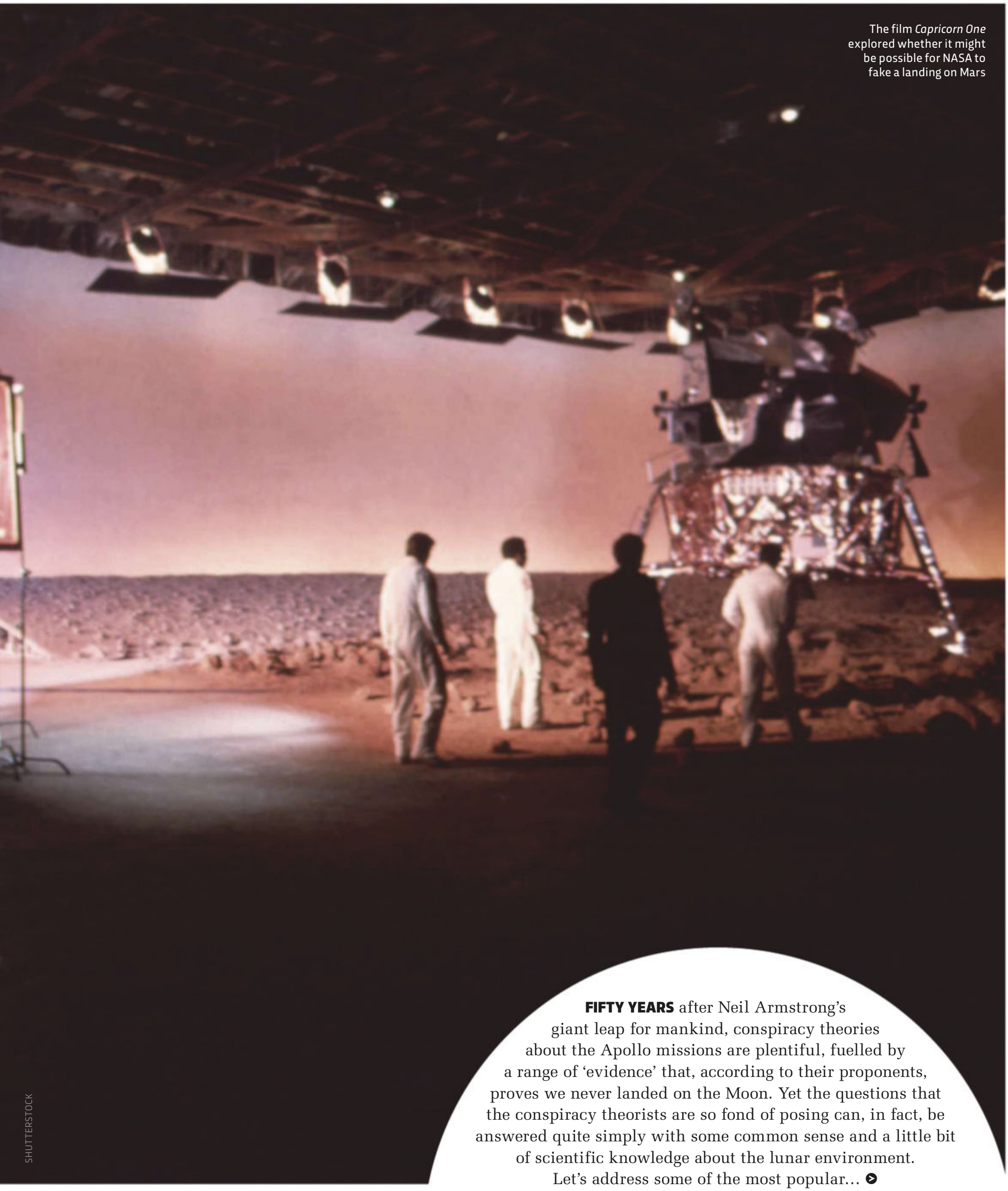
GETTY IMAGES

RETURN

America scored the biggest victory in the space race just after the most intense period of the Cold War and in the face of falling public support for the conflict in Vietnam. Was it mankind's greatest achievement or could it have been an elaborate hoax staged for propaganda purposes?

words by DR MARTIN HENDRY

Were the Moon landings faked?



The film *Capricorn One* explored whether it might be possible for NASA to fake a landing on Mars

SHUTTERSTOCK

FIFTY YEARS after Neil Armstrong's giant leap for mankind, conspiracy theories about the Apollo missions are plentiful, fuelled by a range of 'evidence' that, according to their proponents, proves we never landed on the Moon. Yet the questions that the conspiracy theorists are so fond of posing can, in fact, be answered quite simply with some common sense and a little bit of scientific knowledge about the lunar environment. Let's address some of the most popular… ➲

WHY DOES THE FLAG WAVE, IF THERE'S NO ATMOSPHERE AND, AS A RESULT, NO WIND?

With no wind to spread the flag, it was actually hung from a horizontal crossbar. The flag did wave as the astronauts struggled to plant it in the hard lunar soil, and with no air resistance it continued flapping for a while after they let go. So, if anything, the waving flag is strong evidence that they really were on the Moon.

WHY DON'T THE PHOTOS SHOW STARS IN THE LUNAR SKY?

Because the Apollo landings took place during the lunar day, a combination of direct and reflected sunlight illuminated the lunar landscape brightly. Their photographs required very short exposures to avoid too much light washing them out; these exposure times were simply not long enough to reveal the much fainter stars in the lunar sky.

WHAT ABOUT THE STRANGE ANGLES OF THE SHADOWS IN THE PICTURES?

Hoax theorists claim that non-parallel shadows are evidence of multiple light sources (much like you'd find on a film set) as opposed to one distant source (the Sun). But in a sunlit photograph shadows do appear non-parallel because of perspective, and when they're traced to their start point they meet at the Sun – as several Apollo montages clearly show.

WHY CAN WE SEE ASTRONAUTS CLEARLY WHEN THEY ARE IN THE SHADE?

As noted above, reflected sunlight lit the lunar landscape brightly and could illuminate features on the astronauts' spacesuits even when they were not in direct sunlight.

WHY ARE THERE REFERENCE CROSSHAIRS BEHIND OBJECTS IN SOME PHOTOGRAPHS?

Hoax theorists see this as clear evidence of fakery: they suggest that new foreground objects have been pasted onto photographs, partially obscuring the crosshairs. Closer examination, however, shows that the

RIGHT: Getting the flag to fly on a landscape with no atmosphere required some lateral thinking

FAR RIGHT: Dust thrown up by the Moon buggy's wheels doesn't follow the same trajectory as it would on Earth

BELOW: Simulated moonwalks allowed the astronauts to learn to use tools while wearing spacesuits

A better question to ask is: if the films were played at high speed, would everything look 'normal'?

NASA/JSC X3

crosshairs are not obscured but simply partially washed out by bright objects in the foreground, making them harder to see.

WHY DOES FILM OF THE ASTRONAUTS LOOK LIKE IT'S BEEN SLOWED DOWN?

This effect is due to the Moon's lower gravity. A better question to ask is: if the films were replayed at high speed, would everything look 'normal'? The answer is basically yes, but with some leg movements that Michael Flatley – let alone a spacesuit-clad astronaut – would be proud of in Earth's gravity.

WHY IS THERE NO BLAST CRATER BENEATH THE LUNAR MODULE?

The Moon's lower gravity required only a gentle thrust from the lunar module engine; sufficient to disturb the surface dust, but not to produce a blast crater. Moreover, the effect was confined to a narrow area around the exhaust: there was no atmosphere to extend the disturbance, via a billowing cloud of dust, as expected on Earth. A similar effect is evident with the lunar rover vehicles, or Moon buggies, used during the Apollo 15, 16 and 17 missions: dust thrown up by the buggies' wheels does not float in a cloud but freefalls under lunar gravity.

WOULDN'T THE EARTH'S RADIATION BELTS HAVE BEEN FATAL TO THE ASTRONAUTS?

The main radiation threat was protons – ionised particles from the solar wind – trapped in Earth's Van Allen belts. A few millimetres of aluminium afforded perfectly adequate protection, especially as the astronauts crossed the belts quickly. A major solar flare, producing more penetrating radiation, could have been very serious for the astronauts, but no such event occurred during the Apollo missions.

WHY DO SOME PHOTOS SEEM TO HAVE IDENTICAL BACKGROUNDS, BUT DIFFERENT FOREGROUNDS?

Judging distances in lunar photographs is tricky: the airless environment renders the view of distant landmarks sharper than in terrestrial photographs. In the Apollo 17 scenes in question, a small shift in camera position was enough to take the foreground lunar module out of shot but leave the view of the distant hills unchanged.

WHY WAS THERE NO FUEL JET VISIBLE WHEN THE LUNAR MODULE ASCENT STAGE TOOK OFF?

The lunar module ascent engine burned Aerozine 50 – a mixture of hydrazine and unsymmetrical dimethylhydrazine – that produced a colourless flame, although even a coloured flame would be almost invisible against the sunlit lunar surface.

FINALLY, WHAT SCIENTIFIC EVIDENCE IS THERE TO SUPPORT THE MOON LANDINGS?

Two of the best examples are the samples of Moon rock returned by the six Apollo missions that made it to the lunar surface – the rocks are quite unlike anything found on Earth – and the distance-measuring experiments, still being carried out by scientists to this day, that use laser reflectors left behind by NASA's astronauts. **SF**

by **MARTIN HENDRY** *(@martin_astro)*
Martin is Professor of Gravitational Astrophysics and Cosmology at the University of Glasgow

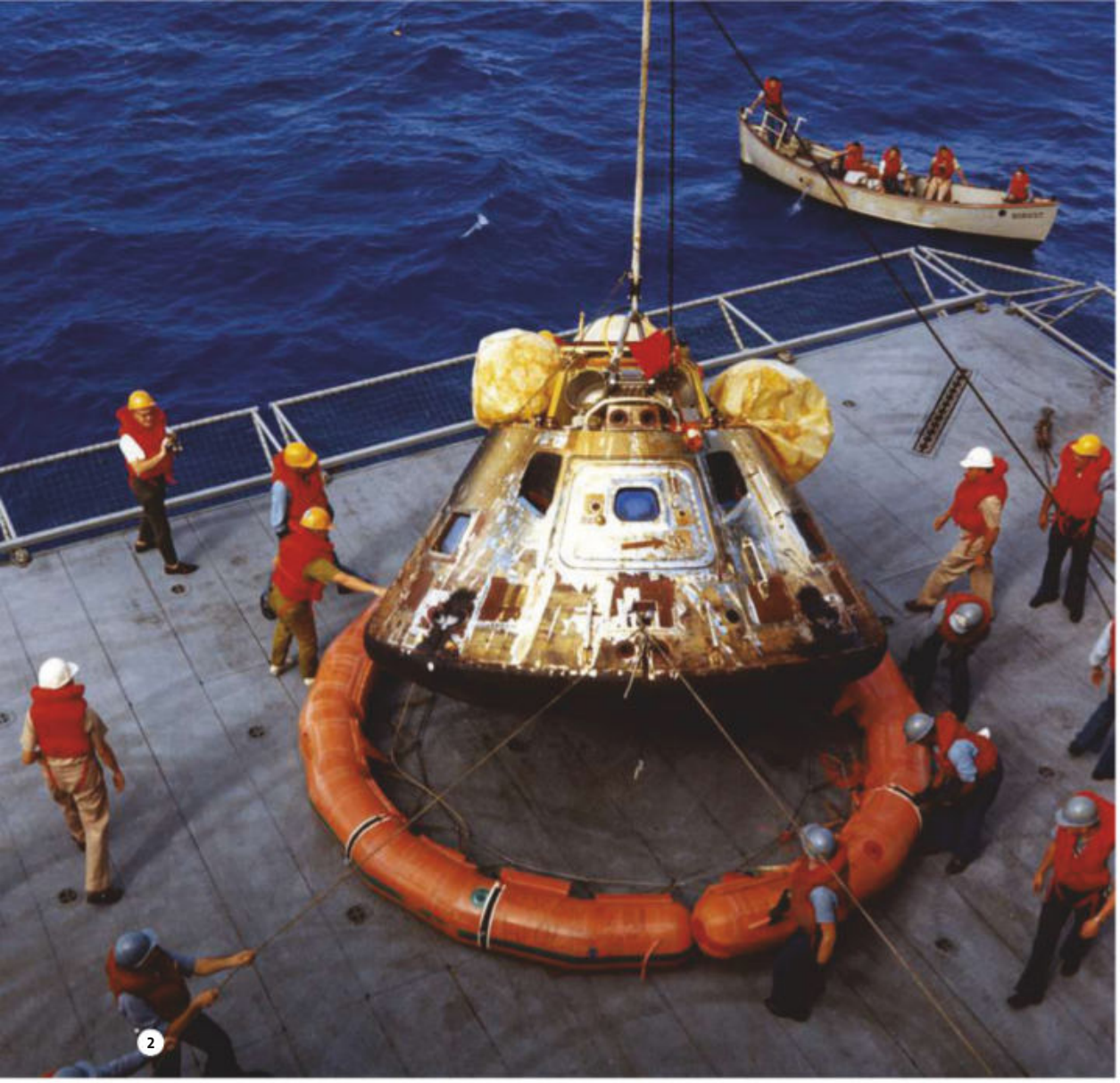
16.50 GMT, 24 JULY 1969

SPLASHDOWN

After enduring the scorching heat generated by falling through Earth's atmosphere, the Apollo 11 mission officially ended when the command module Columbia came to rest on the waters of the North Pacific

1

NASA/JSC X6



1 Half an hour after 'landing', the Apollo 11 crew, dressed in isolation suits, are met and extracted by a navy diver before being airlifted to the USS *Hornet*

2 The command module is lowered onto the deck of the USS *Hornet* before being taken to the Lunar Receiving Laboratory in Houston. The three air sacks at the top inflated to right the module when it came to rest upside-down

3 Just over an hour after splashdown, the crew arrive on the USS *Hornet* and are directed from the helicopter straight into the mobile quarantine facility, a converted Airstream trailer

4 Such was the importance of Apollo 11's safe return that President Nixon joined the USS *Hornet* in the middle of the Pacific Ocean to greet the astronauts, despite being unable to shake their hands

5 26 July 1969. When it arrives in Hawaii, the mobile quarantine facility, still containing the Apollo 11 crew, is unloaded from the USS *Hornet* before being flown back to Houston

6 27 July 1969. Still in their quarantine trailer on arrival in Houston, the crew see their wives for the first time since returning to Earth. From left: Patricia Collins, Jan Armstrong and Joan Aldrin

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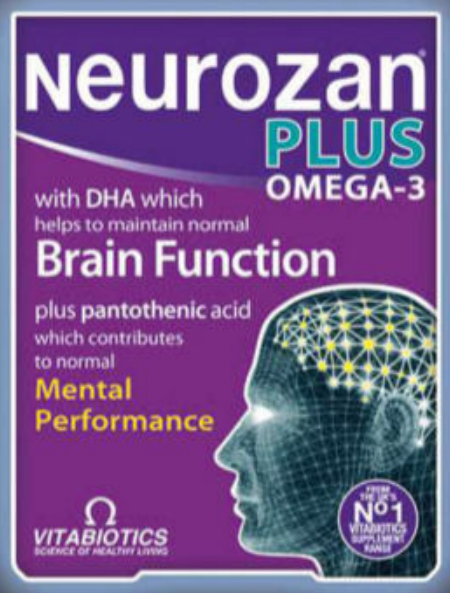

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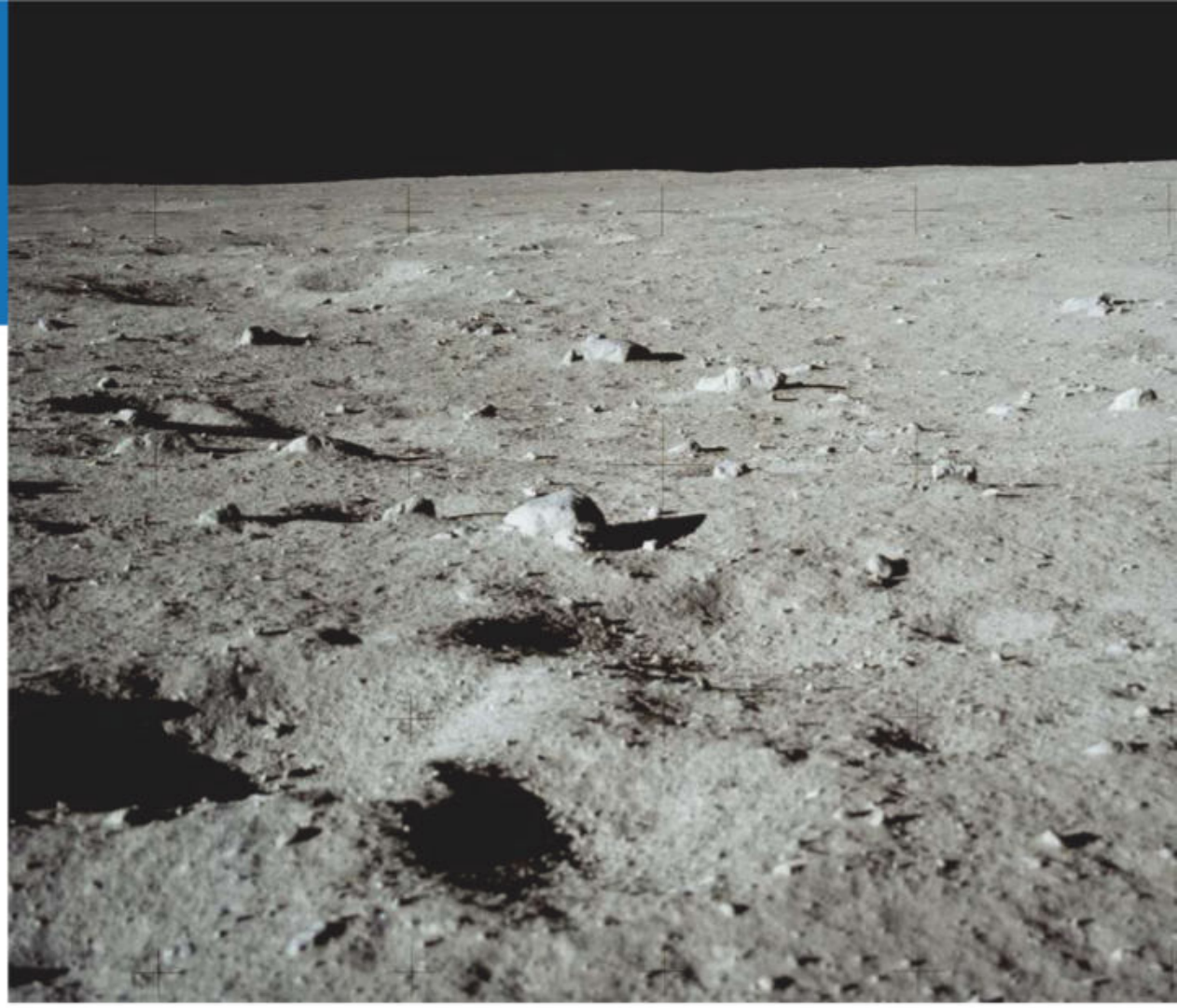
Apollo 11 brought back the first samples from the Moon – seen here arriving at the Lunar Receiving Lab in Houston, Texas

GETTY IMAGES

COME BACK WITH SOME ANSWERS

The purpose of going to the Moon wasn't just to prove that we could. Apollo 11's crew was also tasked with collecting the first samples from the surface of another world in the hope that they could help us answer some fundamental questions regarding its and our origin

words by DR WENDELL MENDELL



In the months before Apollo 11 landed on the Moon, there was intense debate among scientists about how the Moon had formed and what it was made from. Had it gone through a period of partial or complete melting in its history, or had it formed at low temperatures? And what about its surface features: was the proliferation of craters the result of asteroid collisions over aeons?

It was hoped that the samples of lunar rock Buzz Aldrin and Neil Armstrong were tasked with collecting during their time on the Moon would provide the answers to these questions. Upon their return, scientists would at last get their hands on parts of this alien world to analyse for more definitive answers about the nature of the Moon.

On one side of the debate were the geoscientists, who thought that the Moon was like the Earth, with a dense core – still molten – surrounded by a mantle and a thin crust. On the other hand were those who believed that the Moon was a very different kind of astronomical body, with a surface shaped by forces entirely alien from those that moulded the surface of the Earth.

It was hoped that the samples returned by the Apollo 11 crew would provide evidence that could settle the debate once and for all.

LAKES OF LAVA

On the night before Apollo 11 blasted off to begin its journey to the Moon, American television aired a live debate between geologists on whether lunar craters were volcanic calderas or impact features. Related to this was the debate raging over how old the lunar surface was. Most geologists believed it to be hundreds of millions of years old, consistent with the age of the Earth's terrain. Only a minority argued that the surface was primordial, dating to the time of planetary formation. Some lunar researchers even speculated that the meandering lunar rilles – long, narrow channels on the Moon's surface – might be evidence for ancient rivers.

This was the background into which Apollo 11 delivered 22kg of lunar rocks gathered from the Sea of Tranquility. One of the first findings from the analysis of the samples was that the main rock type in the collection was basalt, a volcanic rock similar to basalts on Earth. Here was certain proof that the dark lunar seas were lava lakes.

But nestled in amongst all the small rock fragments, the scientists also found some light-coloured specimens of anorthosite – a rock type made up mainly of calcium-rich feldspar, which was not predicted to be on the Moon. The colour suggested that these few fragments had come from the lunar highlands, a considerable distance away.

Anorthosite is relatively rare on Earth and the vast volume of this rock spread over most of the surface of the Moon seemed highly peculiar. The situation required a radical idea to explain it and one was provided by Prof John Wood,

ABOVE: The samples were collected from rocky areas surrounding the Apollo 11 landing site

BELOW LEFT: Cavities in the returned samples of lunar basalt were caused by gas or steam expanding while the rock was solidifying

NASA/JSC X3

BBC TWO

Learn more about the lunar rock samples in ***The Planets Revisited***
bbc.in/2DnZart

WHAT BECAME OF THE MOON ROCKS?

Apollo 11 was the first mission to bring back samples of rock, soil and dust from the lunar surface but it wasn't the last. The six Apollo missions that landed on the Moon between 1969 and 1972 returned a total of 382kg of lunar material but, somewhat surprisingly, only a fraction of it has so far found its way into laboratories for analysis.

Some of the samples collected by Apollo 11 and 17, the first and last missions to land on the Moon, were gifted to each of the 50 states of America and other nations around the world by the Nixon administration. But as of today, the whereabouts of more than half of those gifts cannot be confirmed. Some have gone missing (such the samples given to Brazil, Canada and Sweden), others have been stolen or sold (including Malta's and Romania's) and one was mistaken for debris left behind after a fire and accidentally thrown out (Ireland's).

The scarcity of the Moon rocks returned by the Apollo astronauts makes them a valuable commodity, and with so many missing and unnaccounted for, a lucruative black market has emerged in which the rocks are bought and sold. Most of the rocks being traded are counterfeit, however. To combat this and attempt to locate some of the missing genuine rocks, an undercover project, called Operation Lunar Eclipse, was set up, led by senior special agent Joseph Gutheinz and to date has managed to recover 78 of the lost samples.

In March 2019, NASA announced it will be opening some of the remaining sealed samples for analysis using the latest technology and methods in order to inform future missions to the Moon.

In a vacuum chamber at the Lunar Receiving Laboratory in Houston, 5.5kg of rocks from the Moon are carefully unloaded for analysis

then a planetary scientist at the Smithsonian Astrophysical Observatory.

His 1970 hypothesis built on earlier theories that the Moon was formed from a collision between the young Earth and a body the size of Mars – an idea that has stood the test of time. Prof Wood suggested that as material came together to form the Moon, so much heat built up that its entire surface became covered in a global magma ocean 100km deep. In this molten rock, the lighter feldspars rose to the surface to form a crust of anorthosite, which slowly cooled to become the light-coloured lunar highlands. The magma ocean concept was new but is now widely accepted as an early stage in the formation of all the terrestrial planets, including Earth.

ANCIENT AND UNCHANGING

The sample collection also included rocks made of fragments that had been melted together by the heat from asteroid and meteorite impacts. Known as breccias, these testified to the intense bombardment the lunar surface underwent during its history.

All the samples showed that the Moon was dry and lifeless, with no organic compounds. The Apollo 11 samples were also pivotal in dating the lunar surface. Geologists had inferred that more densely cratered sections of the surface were older, but there was no way of knowing how old. When the lunar basalt samples were found to be 3.6 billion years old, geologists realised that even the younger sections of the lunar surface were far older than the oldest existing surface features on Earth (believed to be the Negev Desert in Israel, which is thought to been in its current state for around 1.8 million years).

Scientists now estimate that 80 per cent of what we know about the Moon came from the Apollo 11 samples. And the findings went further, having a huge impact on ideas about the early history of Earth and the formation of the Solar System. **SF**

by **Dr Wendell Mendell**
Dr Mendell is a planetary scientist who worked for NASA's Astromaterials Research and Exploration Directorate

WHY WE NEED

TO GO BACK

It's been almost half a century since humans last ventured beyond Earth's orbit. But resolve is growing for a return to the Moon

words by DR STUART CLARK

BBC FOUR

Watch ***The Sky At Night*** *to see who'll be next to go the Moon*
bbc.in/2OcT67G

On 14 December 1972, Gene Cernan, the mission commander for Apollo 17, stood at the foot of the lunar landing module and said, "…I take man's last step from the surface, back home for some time to come – but we believe not too long into the future." He was the 12th person to walk on the Moon, and clearly anticipated a relatively prompt return. That was not to be, as ambitions – if not funding – turned towards Mars. No one has walked on the Moon since.

Now the tide is turning. After years of interest in the Red Planet, the scientific, astronautical and entrepreneurial community is uniting behind a push to return to the Moon, both to continue the research that was started by the Apollo missions and to prepare for future exploration.

Over the following pages, we speak to five leading voices from the worlds of astronomy, philosophy, science and technology to understand why we should return to the Moon, and provide a few glimpses into the national projects most likely to get there next.

NASA

PROF LEWIS DARTNELL

Astrobiologist,
University of Westminster, UK

The only astrobiological reason that you need to justify a return to the Moon is that it preserves ancient rocks from the Earth that have been splashed up by big asteroid strikes. And here I want to tip my hat to Prof Ian Crawford, of the University of London, for these ideas.

The Earth is an active and dynamic place. That's important in the emergence of life and its long-term evolution over billions of years. Yet the planet's dynamism poses a problem when you are trying to find the earliest traces of life on Earth, because most of the planet's crust has been destroyed by plate tectonics [the shifting and recycling of the Earth's surface rocks].

The Moon, on the other hand, is a stable, static and even boring place in the sense of active processes. If there were a way to get ancient rocks from Earth up onto the Moon, they would stick around for a long time, as they wouldn't be eroded or destroyed by plate tectonics. This is where asteroid strikes come in. If chips of the Earth got blown off our planet and up into space, the Moon would sweep up that material and preserve it.

So it stands to reason that there are probably ancient Earth rocks on the Moon that could contain microfossils or chemical fossils that would tell us about the origin of life on Earth.

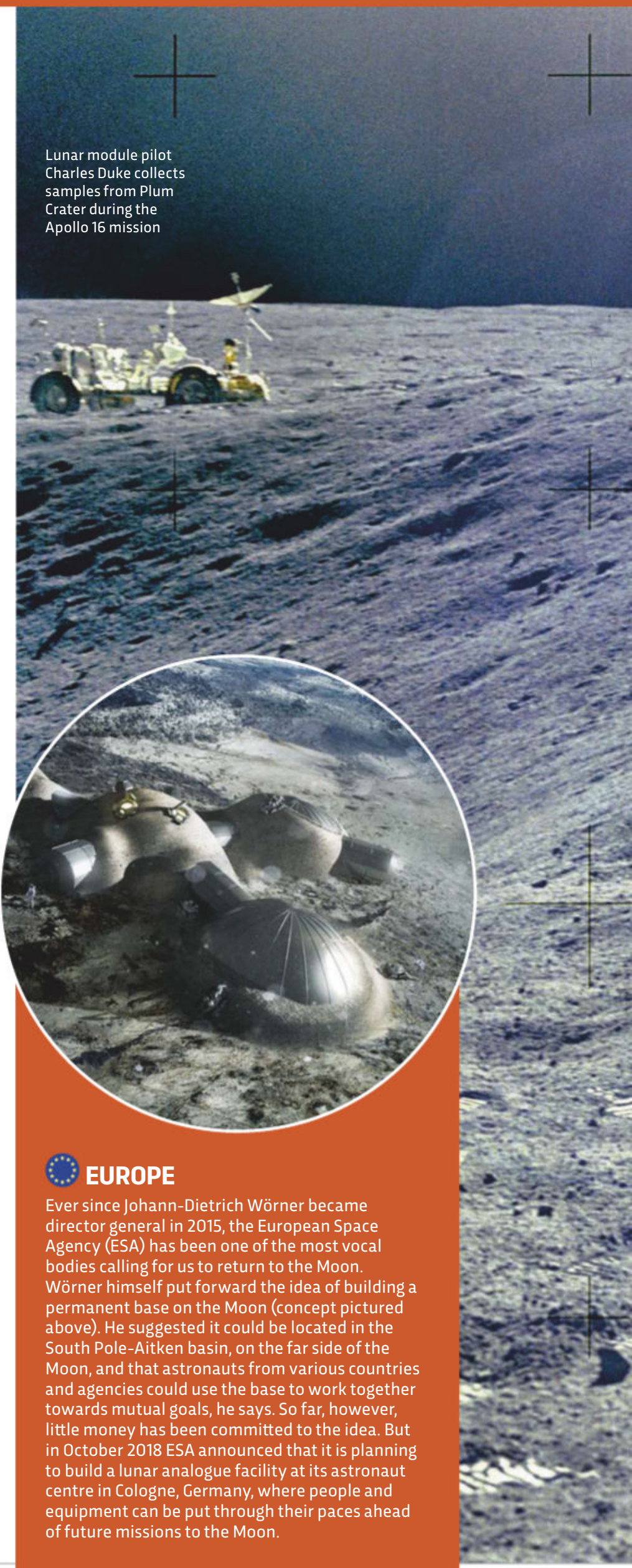
The problem is that it is going to be quite hard to find these flecks of Earth. You might start looking for hydrated minerals, which are ubiquitous on Earth but very rare on the Moon.

Any material splashed up would be distributed randomly across the Moon but you could look for places where that material has been preserved.

The main problem of preserving biosignatures in space is the cosmic radiation. These high-energy particles travel at close to the speed of light, and are destructive when they hit cells of organic molecules. So we might want to target ancient lava flows on the Moon that may have covered up any Earth rocks that were lying on the surface at the time, and are now protecting them beneath several metres of rock.

There would be the issue of mapping to identify and date the lava flows, and then sending a mission to drill on a lava flow of the correct age.

It would be hard work. It would be like looking for a needle in a haystack without the use of a magnet. On the other hand, the pay-off would be enormous. You would be finding Earth rock that is far older than anything found on our planet. So there is a lot to gain from doing this.



Lunar module pilot Charles Duke collects samples from Plum Crater during the Apollo 16 mission

EUROPE

Ever since Johann-Dietrich Wörner became director general in 2015, the European Space Agency (ESA) has been one of the most vocal bodies calling for us to return to the Moon. Wörner himself put forward the idea of building a permanent base on the Moon (concept pictured above). He suggested it could be located in the South Pole-Aitken basin, on the far side of the Moon, and that astronauts from various countries and agencies could use the base to work together towards mutual goals, he says. So far, however, little money has been committed to the idea. But in October 2018 ESA announced that it is planning to build a lunar analogue facility at its astronaut centre in Cologne, Germany, where people and equipment can be put through their paces ahead of future missions to the Moon.

USA

In March 2019, Vice President Mike Pence announced that the US intends to return to the Moon by 2024 and that the next man and first woman to set foot on the lunar surface will both be American. It's an ambitious, possibly unrealistic, target as there are a number of significant obstacles NASA will have to overcome to achieve it, not least of which is the current lack of any kind of lunar lander. Further complicating matters are the continued delays in the development NASA's next-generation rocket, the Space Launch System (SLS). These have forced the administration to push back the unmanned test flight of the SLS and Orion crew vehicle (right), which it had initially scheduled for June 2020.

NASA X3

NAVEEN JAIN

Co-founder and chairman, Moon Express

If I were to paraphrase President John F Kennedy, "We choose to go to the Moon, not because it is easy but because it is great business."

When Moon Express lands on the Moon, we will become the first private company to do so. That is quite symbolic of things to come. To me, the next set of superpowers are likely to be entrepreneurs, not nation states.

The time is now right to use technology to solve the grand challenges facing humanity. I argue that landing on the Moon could potentially bring world peace. We fight over land, water and energy, yet all we have to do is look up into space and there is an abundance of these things.

It is only a matter of time before we get hit by a massive asteroid. If we live only on Earth, then humans are going to become extinct like the dinosaurs. Wouldn't you prefer to have some entrepreneur creating an underlying infrastructure so that we can really become a multi-planet society?

What we will be doing is creating the underlying infrastructure of space. We think of ourselves as the iPhone of space. Back in 2008, Steve Jobs launched the iPhone and the App Store. Obviously he had a seriously good idea of what people could do with the device but couldn't possibly have anticipated the success that both were spurred on to by certain killer apps.

Now that we have created this iPhone for the Moon with Moon Express, we have to ask ourselves what is going to be its killer app. Will it be something that Moon Express will create, or is it something that we'll allow other entrepreneurs to do? It could be bringing stuff down to Earth, or using stuff to create habitats on the Moon.

My gut reaction is that bringing lunar rocks to Earth could be the most beneficial task initially. We could disrupt the diamond industry. Diamonds were never the symbol of love until the 1950s. De Beers created a brilliant ad campaign to sell that idea. If you're an entrepreneur against a monopoly you don't fight it, you change the game. So, we bring back the Moon rock and we change the paradigm: it's not enough to give her a diamond, if you love her enough you give her the Moon.

PROF DAVID ROTHERY

Professor of planetary geosciences,
Open University, UK

Lunar exploration has been going on fairly vigorously for 20 years, but it hasn't involved people since the last Apollo mission. We currently have a series of unmanned missions around the Moon, including NASA's GRAIL (Gravity Recovery And Interior Laboratory) and China's Chang'e 4, which became the first mission to successfully land on and begin exploring the far side of the Moon in January 2019. So the unmanned exploration is happening but there's only so much you can do remotely.

You do need to get people among the surface materials as well – both for seeing the geology at close quarters and for taking measurements that you can't take from orbit. Apollo left four seismometers on the Moon for recording moonquakes. They weren't brilliant but it's the only other planetary body that we've got seismology for. The data the seismometers collected told us about the Moon's interior but they were turned off after a few years to save money.

A few more seismometers on the lunar surface would give us great insight into the Moon's interiors. But you have to be on the surface to deploy them so that you can couple them properly to the ground.

Also there are heat flow experiments. We don't know the rate at which the Moon's internal heat is leaking out towards the surface. They tried to measure it during the Apollo missions but it didn't work. They had trouble getting a good hole into the ground. So we're guessing at the lunar heat flow until we can go back, drill a hole and insert some equipment. And you're probably going to need people to do something that fiddly.

Getting equipment to work on the Moon is a challenge we have yet to overcome. The lunar dust rises and falls with day and night because of electrical static charges, so you can get dust flecks into your mechanisms and that can lead to problems. But if you've got people there you can overcome those problems. They can deploy fresh equipment and drill holes. They can also wander around making geological observations. The orange-coloured lunar soils were spotted by an astronaut from one of the later Apollo missions. He thought it was something rusty but it was orange beads from an explosive volcanic eruption. If you've got trained people at the location, they'll spot the unusual things.

The Mars rovers – impressive though they have been – haven't gone as far as astronauts that drove the Moon buggies around. It's a lot more expensive to get people there, but they get a lot more done.

I was a kid when the Apollo missions happened and I thought it was the future, I thought that was what we were going to be doing: putting people in space. It was inspiration for me. There is a benefit from just seeing people up there because it inspires the next generation of scientists. I don't think you can decouple that from the scientific facts that you are going to find out. As well as the mysteries that you're going to unravel, you're also going to be inspiring the next generation of scientists.

CHINA

On 14 December 2013, China became a true contender in the race to put humans back on the Moon when the country successfully landed its Yutu (Jade Rabbit) rover on the lunar surface. The rover operated for 42 days, and although well short of the planned three months, it was still a major boost for the Chinese exploration programme.

The next major step came in early 2019 when the Chinese National Space Administration (CNSA) became the first to successfully land a mission on the far side of the Moon. China's Chang'e-4 touched down on 3 January and released the Yutu-2 rover, which was still exploring and sending pictures back from the lunar surface in April. The CNSA is also developing a powerful new rocket, the Long March-9 (above), that could potentially take humans to the Moon sometime in the 2030s.

NASA X2, REUTERS

JAPAN

The Japanese Aerospace Exploration Agency (JAXA) has sent two missions into lunar orbit, 1990's Hiten and 2007's SELENE. It's now working towards making its first lunar landing attempt. JAXA's original plans were for SELENE-2, a large 1,000kg lunar lander and 200kg rover. But JAXA has now scaled down its plans. The new mission, dubbed Smart Lander for Investigating the Moon (SLIM), is a smaller, 120kg craft (right) that's expected to attempt a landing on the Moon's surface sometime around 2021.

The Moon's lack of atmosphere means impressions left by the Apollo astronauts in the lunar surface are likely to still be intact today

GONZALO MUNÉVAR

Philosopher, Lawrence Technological University, Michigan

Philosophy has to do with understanding our relationship with the world. In that sense, it is inextricably bound to science. It seems to me that the philosophical concern of this is what happens if we go to places like the Moon.

We can look at what has already happened. By going to the Moon, with Apollo and other missions, we have come to understand better what the Earth is like. So knowledge of the planetary system and of the cosmos gives us knowledge of the Earth. It is not just idle curiosity; it is something that, in the long run, affects us because it makes us understand our place in the Universe, and once we understand the Universe – and this is the point of practically all knowledge – we can then interact with that world better.

For us, understanding what the Earth is like is extremely important because the Earth has changed. To understand that, we need to know what kind of planet Earth was when it formed and what kind of forces have acted upon it. One of the most important objects that we have to study is the Moon. By going to the Moon only a few times we accumulated an extraordinary amount of knowledge about what the Earth was like because the Earth and Moon apparently formed together. Even if this is not the case, it is still important to find out how the Earth and the Moon came to be together like they are.

The lack of atmosphere and activity on the Moon means its surface has a permanent record of collisions with comets and asteroids [in the form of craters], of a size and number that we do not have on Earth. The Moon knows so much.

To understand the Earth is to understand the Earth as a planet, which means to understand what planets are, how they formed, how they evolved and how they relate to the Sun and so on. The Moon is so close to us. So going back to it is going to help us improve our understanding of our place in the Universe.

Exploring with humans is a lot more expensive and dangerous than doing it with machines but in the long run we have to do it any way. It also provides other benefits because humans are much more adaptable than robots.

Steve Squires, the person in charge of the Mars rovers, once said that he was very pleased with everything one of them had done in the previous six months. But he also pointed out that an astronaut could have done it all in a single day.

It is great that we have those machines, but eventually we need to be out there. I also think it is good to have adventures as a species so that more people can be inspired by them and participate in their own.

Going to the Moon the first time around was so exciting. Going back will give us the opportunity to go to other, more exciting places."

Apollo 17's lunar module pilot and scientist Harrison Schmitt explores the Van Serg Crater in the lunar roving vehicle

INDIA

Following the success of its first lunar probe, Chandrayaan-1 (left) in 2008, the Indian Space Research Organisation announced a follow-on mission. Whereas Chandrayaan-1 carried instruments provided by NASA, ESA and the Bulgarian Aerospace Agency, Chandrayaan-2 was meant to be a collaboration with Russia. When the Russians failed to deliver the promised lander in 2013, India decided to go it alone. The mission will carry an all-Indian payload of orbiter, lander and rover, and is expected to launch in July 2019.

COMMANDER CHRIS HADFIELD

Astronaut, first Canadian to walk in space

Exploration is what teaches us things. It allows us to make educated and informed decisions. If we never explore then we cannot improve and expand. Exploration is fundamental to human nature. It is why we learn to walk before we learn to talk, because we have to explore to become well-formed human beings. And we have to have exploration as part of our society in order to be a well-formed society.

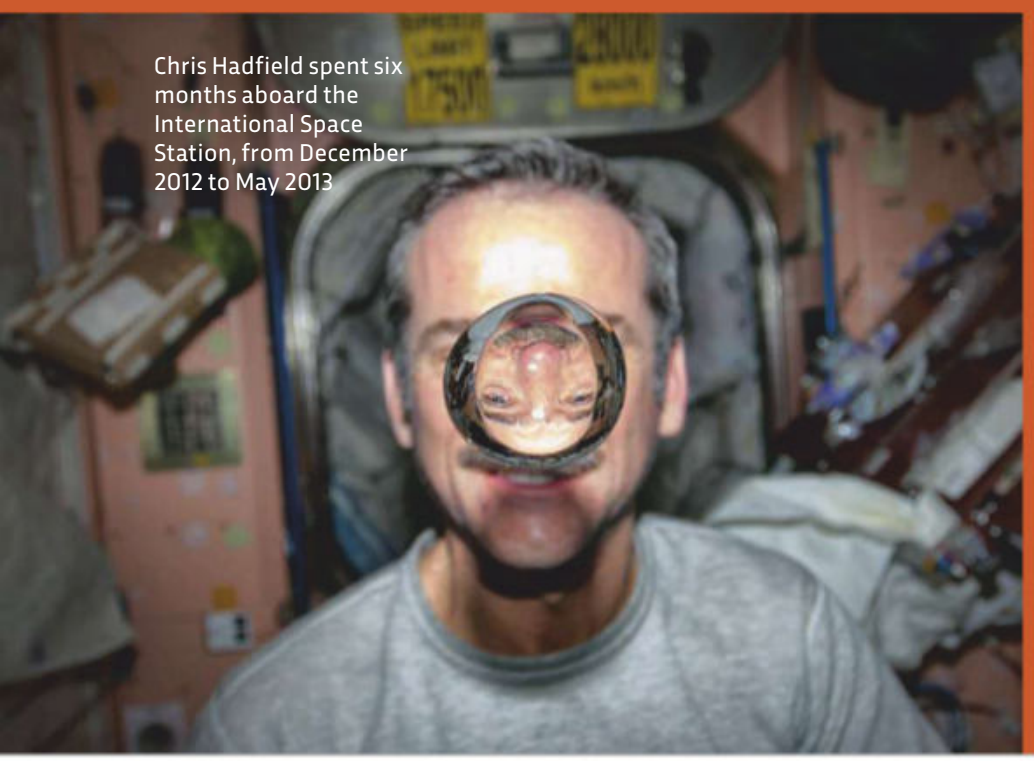
There are so many precedents in history. I look at the businessmen of England in 1496 who were hesitating about what to do in the wake of Columbus's discovery of America, "Well, okay he's discovered a new world but should we do anything? Is there a quick buck to be made?" But then a few far-sighted people in Bristol and a few in London said, "I think exploration is going to lead to good things. It is going to take a while to get any money back but let's fund John Cabot." And Cabot's 1496 voyage was a complete bust. Cabot launched out of Bristol in one ship and didn't know what he was doing. But he learned a lot.

He came back, set out again in 1497 and then discovered Newfoundland. He opened North America to England and began the great English exploration over the next 300 years.

A lot of the world is uninhabitable without technology. But once you develop the right sort of technology, then living in those places can have enormously valuable consequences for humankind. The real question is at what point does our technology become advanced enough to make exploration economically viable? How much can be done by sensor equipment alone and how do we determine when people should go? We can stick a weather station in Antarctica and it will tell us the air temperature and the windspeed. But that is such a tiny piece of the information that we need to know about Antarctica. Most of the data needs to be inquisitively pursued and robots are terrible at doing that.

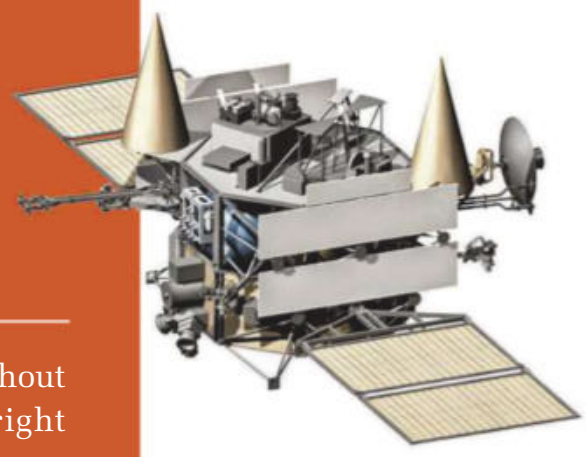
So should we forsake lunar exploration for Martian exploration? They're both largely unknown. The real question is how do we not blow it? How do we not make fatal mistakes? We're going to get it wrong. On my three visits to the International Space Station, things went wrong all the time. You would have a hard time counting the number of times that we needed to be saved by bringing replacement equipment up from Earth.

If we go to Mars for a six-month voyage, then we are basically trapped in our own ignorance. It could end up being like the Franklin expedition, where you think you know what you're doing but you inadvertently kill everybody. We have to recognise that failure is a big, big part of success, so you have to give yourself the opportunity to fail without destroying the entire effort that you are trying to accomplish. **SF**



Chris Hadfield spent six months aboard the International Space Station, from December 2012 to May 2013

by **DR STUART CLARK** *(@DrStuClark)*
Dr Clark is an astronomy journalist and a fellow of the Royal Astronomical Society. His latest book is ***The Unknown Universe***



RUSSIA

In May 2014, Russian newspaper *Izvestia* published a government document purported to show that the Russian space agency, Roscosmos, was drawing up plans for a manned Moon landing in 2030. Its ambitions were confirmed in October 2015 when Vladimir Solntsev, the then head of Roscosmos, told reporters that the country plans to send a crew to the Moon in 2029.

Meanwhile, the Russians are ramping up their robotic exploration programme. Roscosmos is currently working on a range of orbiters and landers called Luna-25, Luna-26 (concept pictured) and Luna-27. The idea is that the landers will explore the lunar south pole, prospecting for resources such as minerals and water ice that could be used to sustain a human outpost.

BBC TWO

Listen to an episode of ***In Our Time*** *about the Moon* bbc.in/2FIOjdL

A new perspective

After centuries of being limited to looking at the objects in the skies, humanity finally managed to reach out and touch one on 20 July 1969. Fifty years later, the Apollo 11 Moon landing remains one of our most significant achievements and marks the moment when our physical exploration capabilities extended beyond Earth. The realisation that, with sufficient will, effort and cooperation, we could visit other worlds gave us a greater insight into our own – both our complete reliance upon it and its fragility. Seeing and sampling the 'magnificent desolation' of the lunar surface at first hand served to highlight our responsibility to caring for and conserving the bountiful variety of landscapes and life that have emerged and exist on our home planet.

NASA/JSC

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